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Sludge Characterization Studies

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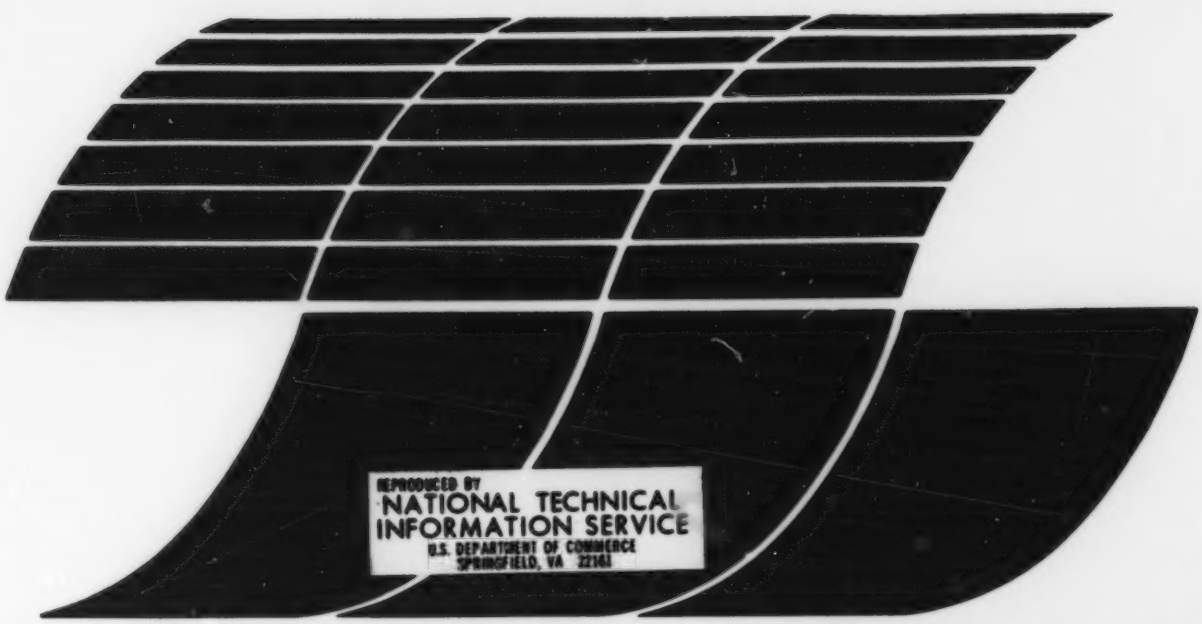

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16. ABSTRACT The report gives results of slurry and solids characterization studies of 167 samples from the TVA/Shawnee turbulent contact absorber and venturi-spray tower scrubbing systems. It summarizes the range of variability of solids and correlation of this variability with plant operating conditions. It gives regression models characterizing settled solids and bulk density as functions of calcium sulfite solids and solids recirculated. Systems using limestone as absorbent precipitate $CaSO_3 \cdot 0.5H_2O$ primarily as single plates and relatively flat rosettes; spheroidal aggregates of many small plate crystals result when lime is used. Sulfite crystal morphology is independent of scrubber configuration. For limestone systems, crystal size is clearly related to stoichiometric ratio (Ca:S); no such relationship is observed for lime systems. Precipitation and crystal growth rates are believed responsible for the difference in sulfite crystal morphology observed between the lime and limestone systems. For forced oxidation with either absorbent, the reaction products have very large, blocky $CaSO_4 \cdot 2H_2O$ crystals; no $CaSO_3 \cdot 0.5H_2O$ forms are seen. The peak area (thermal analysis) resulting from gypsum dehydration is linearly proportional to gypsum concentration. A clear distinction between gypsum SO4(-2) and substituted SO4(-2) in the sample is the basis for the $CaSO_4 \cdot 2H_2O$ determination method used.

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Sludge	Calcium Carbonates	Stationary Sources	07A
Analyzing	Calcium Oxides	Characterization	14B
Properties	Gypsum	Calcium Sulfites	08G
Gas Scrubbing			13H
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ABSTRACT

This report summarizes work completed during the period March 13, 1975, to June 30, 1977. The main emphasis of this work was to determine the range of variability of the solids from scrubbers operated at the Shawnee test facility and to attempt to correlate this variability with plant operating conditions. Slurry and solids characterization studies were conducted on 167 samples obtained from the turbulent contact absorber (TCA) and venturi-spray tower scrubbing systems.

Systems operating with limestone as the absorbent precipitate $CaSO_3 \cdot 0.5H_2O$ primarily as single plates and relatively flat rosette forms, while spheroidal aggregates of many small plate crystals are formed when lime is used. The form of sulfite morphology observed is shown to be independent of scrubber configuration. Clear evidence is seen of the relationship between the crystal size (in limestone systems) and system Ca:S ratio (stoichiometry), although no such relationship is observed in lime systems. The difference in sulfite crystal morphology observed between lime and limestone systems is attributed to precipitation and crystal growth rates. When forced oxidation is used with either absorbent, the reaction product is seen to consist of very large, blocky $CaSO_4 \cdot 2H_2O$ crystals; no $CaSO_3 \cdot 0.5H_2O$ forms are seen.

A simple and rapid method for the determination of gypsum in scrubber solids (over the range 0.1 to 10.0 wt. percent) was developed. The peak area resulting from gypsum dehydration (using differential scanning colorimetry) is directly and linearly proportional to the concentration of gypsum in a sample. This peak is not obscured or interfered with by other components in the sample matrices and thus provides a clear distinction between gypsum $SO_4^=$ and substituted $SO_4^=$.

Statistical analysis of the venturi-spray tower data resulted in regression models which characterize the percent settled solids and percent bulk density as a nonlinear function of calcium sulfite solids and the percent solids recirculated. Behavior of the solids produced by both lime and limestone systems are summarized for low and high levels of oxidation.

High levels of settled solids (50 percent or more) for both the lime and limestone product sludges are associated with high oxidation, high percentage solids recirculated, high fly ash content, and low sulfite solids. Low percentages of settled solids (35 percent or less) for both systems occur with low levels of solids recirculated, average oxidation, low fly ash content, and high levels of carbonate.

High levels of settled bulk density, for lime and limestone product sludges, of 1.4 g/cc or more are characterized by high oxidation, high levels of solids recirculated, high fly ash content, and low sulfite solids. As a contrast, low fly ash content, high percentages of sulfite and carbonate, and solids recirculated plus low oxidation are noted for settled bulk densities of 1.2 g/cc or less.

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Section 1

INTRODUCTION

Sludges produced by flue gas desulfurization processes have been extensively characterized both chemically and physically in the past, but usually this type of study has been only of short duration, not defining the total range of variability of the solids or relating any of the characteristics to scrubber operation. With the increasing use of sludge treatment processes, this lack of research in solid characterization presents problems when designing such systems for economy and efficiency of operation, since the chemical and physical makeup of the sludges directly impacts the handling and disposal requirements.

One of the purposes of this study has been to provide a long-term, comprehensive chemical and physical characterization of lime and limestone scrubbing sludges produced at the Shawnee Test Facility. Where possible, a collateral goal has been to relate sludge properties such as settling rate and final (settled) bulk density and solids content to process operating conditions such as initial sludge solids content, hold tank residence time, system Ca:S stoichiometry, presence of fly ash, sludge pH or temperature, liquor chemistry, etc. This study also has included investigations on the conditions of optimum crystal growth because of the significance of this factor on pond site dewatering, filtration rates, and liquid entrainment in the solids.

This report presents all data collected on samples taken from the turbulent contact absorber (TCA) and venturi/spray tower systems over the period of study March 13, 1975, to June 30, 1977.

This investigation has used comparative optical and electronic microscopy, x-ray diffraction, infrared spectrophotometry, and thermal analysis to provide a comprehensive study of the range of variability observed in sludge phases from the Shawnee scrubbers. Settling rates and determinations of the final solids content and bulk densities provide data on the physical properties of sludges.

Statistical analysis of the venturi/spray tower data resulted in regression models which characterize the percent settled solids and percent bulk density as a nonlinear function of calcium sulfite solids and the percent solids recirculated. Behavior of the solids produced by both lime and limestone systems are summarized for low and high levels of oxidation.

A simple and rapid method for the quantitative determination of gypsum in scrubber solids (over the range 0.1 to 10.0 wt. percent) was developed. This method differentiates between gypsum $SO_4^=$ and substituted $SO_4^=$.

Section 2

CONCLUSIONS AND RECOMMENDATIONS

Solids produced by the TCA and venturi/spray tower at the Shawnee Test Facility from March 13, 1975, to June 30, 1977, have been characterized chemically and physically. It has been shown that the primary sludge component affecting handling and disposal is $CaSO_3 \cdot 0.5H_2O$ and that the form in which this compound is precipitated is an important factor. Systems operating with limestone as the absorbent precipitate the $CaSO_3 \cdot 0.5H_2O$ primarily as single plates and relatively flat rosett forms, while spheroidal aggregates of many small plate crystals are formed when lime is used. The form of sulfite morphology observed is shown to be independent of scrubber configuration. In limestone systems, SEM photomicrographs document an inverse relationship between the crystal size and system Ca:S stoichiometry. No such relationship is observed in lime systems. The difference in sulfite crystal morphology observed between lime and limestone systems is attributed to precipitation and crystal growth rates. When forced oxidation is used with either absorbent, the reaction product is seen to consist of very large, blocky $CaSO_4 \cdot 2H_2O$ crystals; no $CaSO_3 \cdot 0.5H_2O$ forms are seen.

Sludges produced by both lime and limestone systems are shown to display zone settling characteristics in the region above an artificial lower limit of 10 to 12 percent solids; here, settling rates are seen primarily to be a function of initial sludge solids content, although solids morphology effects are seen. At initial sludge solids contents of 10 percent or less, it is seen that clarification settling applies and that lime slurries settle faster. When forced oxidation is used with the precipitation of large gypsum crystals, settling rates are shown to be five to ten times faster than normal lime- or limestone-produced slurries in the same range of solids content. Gypsum slurries are shown to settle to a much higher final solids content than either lime- or limestone-derived slurries. In lime and limestone systems, there are indications that the presence of fly ash causes an increase in final (settled) solids content. While in this study lime and limestone slurries are shown to retain approximately the same final solids content after static settling in a closed cylinder, other evidence is provided that shows lime slurries dewater with more difficulty because of the generally higher surface area of their solids components.

Thermal analysis of the dried slurry solids shows that the thermal desolvation of the $CaSO_3 \cdot 0.5H_2O$ component is complex, lending support to the suggestion that this component may be substituted to varying degrees with $SO_4^=$ or $CO_3^=$. The range of variability observed in measurements of this compound's crystallographic properties also supports this premise, although attempts to show correlations between the temperature of desolvation and crystallographic parameters were unsuccessful.

A simple and rapid method for the quantitative determination of gypsum in scrubber solids was developed. Thermal analysis of dried scrubber solids was employed using differential scanning colorimetry. It was shown that the peak area resulting from gypsum dehydration is directly and

linearly proportional to the gypsum concentration in the scrubber solids. This peak is not obscured or interfered with by other components in the solids matrices and thus provides a distinction between gypsum $SO_4^=$ and substituted $SO_4^=$. Over the range if 0.3 to 10 percent gypsum, determination may be made with a precision of better than 5 percent and an accuracy of better than 5 percent.

Through statistical analysis of sludge data, it was shown that high levels of settled solids (50 percent or more) for both the lime and limestone product sludges are associated with high oxidation, high percentage solids recirculated, high fly ash content, and low sulfite solids. Low percentages of settled solids (35 percent or less) for both systems occur with low levels of solids recirculated, average oxidation, low fly ash content, and high levels of carbonate.

High levels of settled bulk density, for lime and limestone product sludges, of 1.4 g/cc or more are characterized by high oxidation, high levels of solids recirculated, high fly ash content, and low sulfite solids. As a contrast, low fly ash content, high percentages of sulfite carbonate, and solids recirculated, plus low oxidation are noted for settled bulk densities of 1.2 g/cc or less.

It should be noted that the main objective of the Shawnee Test Facility is to evaluate various scrubber concepts and that the sludge characterization study was a side effect to this scrubber evaluation. As a result of this, no specific tests were conducted on the scrubber to control the characteristics of the sludge produced. Since the sludge characterization study has shown specific correlations between scrubber operation and sludge characteristics the next step should be to verify and demonstrate these correlations through actual control of scrubber operation. Thus, a study should be made where the operation of the scrubber is dedicated to sludge production and characterization evaluations. This type of study could best be accomplished at a scale smaller than Shawnee for economical purposes.

Section 3

INSTRUMENTAL TECHNIQUES OF CHARACTERIZATION

During the period March 13, 1975, to June 30, 1977, slurry and solids characterization studies have been conducted on 167 samples obtained from the TCA and Venturi/spray tower scrubbing systems located at the Shawnee Test Facility. A number of instrumental techniques have been employed in this characterization. Scanning electron microscopy (using a Cambridge S-4 SEM) and optical microscopy provided both qualitative and quantitative information concerning bulk solids composition, as well as the specific morphological form in which various individual components occur. Infrared spectrophotometry (using a Perkin-Elmer 521 grating instrument) and x-ray powder diffraction measurements (using Phillips-Norelco x-ray generators and goniometers) have been used for semiquantitative analyses of the dried solids and to determine crystallographic unit-cell parameters of $CaSO_3 \cdot 0.5H_2O$. The specific surface area of the dried solids was determined as an indication of solids component morphology. Since a portion of this study involves investigation of the degree to which the calcium sulfate hemihydrate component may have been substituted by sulfate or carbonate species, several techniques have been used which would reflect any changes in crystal structure caused by this substitution. Optical microscopy was used to provide the index of refraction of this component, while its specific crystallographic unit-cell parameters, as determined by x-ray diffraction, are very sensitive to compositional changes. In addition, differential scanning calorimetry (DSC) using a Perkin-Elmer DSC-2 was evaluated as an indicator of the ease with which the sulfite component underwent dehydration. It was felt that the temperature of dehydration should, in general, vary inversely with the degree of substitution of sulfate for sulfite.

Slurries obtained from the scrubbing systems were characterized by static settling tests. Values for the settled bulk densities and settled percent solids also were determined.

The results of the chemical and physical examination of the slurries and solids are presented in Tables 1 and 2. A discussion of specific areas of investigation follows.

Section 4

SOLIDS MORPHOLOGY

Solids samples obtained from the TCA and venturi/spray tower, when operated under nonoxidizing conditions, generally contain calcium sulfite hemihydrate and fly ash as the major species. Small quantities of gypsum, unreacted absorbent, and quartz are also present.

Sulfite Morphology

The calcium sulfite hemihydrate species is generally the major component (50 to 70 percent by weight) of the solids. A study of its morphology and occurrence is important since these factors bear heavily on handling considerations such as sludge filtration, clarification, and disposal technique. It should be noted throughout this report that the crystalline species referred to as calcium sulfite hemihydrate may be more appropriately described as $Ca(SO_3)_x(SO_4)_y \cdot zH_2O$ or $(CaSO_3)_x(CaSO_4)_y \cdot zH_2O$ where x is much greater (in the range of 10 times greater) than y and z approaches 0.5.

The specific physical form in which the sulfite species appears is directly related to the type of absorbent used (lime or limestone) and is independent of the scrubber configuration (TCA or venturi/spray tower). The calcium sulfite hemihydrate component of the solids samples received during this study occurs in several forms (see Figure 1 for examples). When limestone is used as the absorbent, the sulfite crystallizes predominantly as well-formed single plates with a length-width-thickness average ratio of 25:20:1 (Figures 1A and 1B). While within a given sample, the crystal size distribution will range over an order of magnitude, the average size may differ only by a factor of two to three from one sample to another within the same run. The sulfite crystals in Figures 1A and 1B show the general maximum and minimum sizes observed in limestone runs during this study. While the single plates described above are the major form observed, aggregated forms of the sulfite crystals also are seen. An example of a form appropriately described as a flat or two-dimensional "rosette" in which many small plates grow outward in all directions, particularly at low angles, around an axis perpendicular to the plane of growth is shown in Figure 1D. This form is not uncommon; most samples examined from limestone-scrubbing operations will contain some incidence of this rosette form. A few samples have shown this form as the predominant sulfite occurrence. A more open form of aggregate resulting from the use of limestone is shown in Figure 1C. These forms consist of interpenetrating plates forming relatively open structures of varying size and shape; their occurrence in small amounts is a common feature.

The characteristic form of the sulfite precipitated from scrubbing liquors where lime is used as the absorbent is shown in Figures 1E and 1F. These generally spherical aggregates do not show a wide variation (usually less than an order of magnitude) in size distribution within a given sample, although incompletely developed forms and fragments are often seen. Examination of these spherical aggregates with transmission electron

microscopy was undertaken to determine whether or not the aggregates possessed a central core of nonsulfite material (i.e., fly ash) which may have served as an initial nucleation site. Results obtained with this method were inconclusive due to particle decomposition and fragmentation by beam heating effects. It may be noted, however, that spherical aggregate formation is commonly seen in lime scrubbing operation under fly ash-free conditions. Therefore, to clearly demonstrate that the sulfite habit is scrubber-independent and absorbent-dependent, the samples obtained from the venturi/spray tower scrubber over the period March 13, 1975, to June 27, 1976, may be subdivided into five separate groups:

A. 3-13-75 to 10-5-75, lime scrubbing, Figure 2
B. 10-12-75 to 1-31-76, limestone scrubbing, Figure 3
C. 2-15-76 to 3-2-76, lime scrubbing, Figure 4
D. 3-6-76 to 4-21-76, limestone scrubbing, Figure 5
E. 5-1-76 to 6-27-76, lime scrubbing, Figure 6

During this period the use of limestone as the absorbent was alternated with that of lime as seen above. The results repeatedly show the spherical sulfite aggregate occurrence (Figures 2, 4, and 6) when lime is used. When limestone is used, however, flat plates are seen to predominate (Figures 3 and 5). A probable cause for this clearly-established absorbent-morphology relationship appears to lie in the difference in precipitation rates for the two forms; i.e., the spherical aggregates formed under lime scrubbing operation are a result of much faster sulfite precipitation than the larger single plates formed with limestone operation. Several factors argue in favor of this explanation. One of the most significant features is the obviously greater complexity of the sulfite forms precipitated when lime is used. Complex crystalling forms; rather than larger single crystals, are commonly observed when precipitation rates are high. Also, the optical and x-ray crystallographic properties (index of refraction, lengths of unit-cell axes) show greater variation in the lime-derived sulfite. These properties are very sensitive to variations in the crystal structure of the compound caused either by inclusion of ions "alien" to the parent lattice (Na^+, K^+, $SO_4^=$, $SO_3^=$, etc.) or by large scale lattice defects of a nonstoichiometric nature. Both foreign ion inclusions and lattice defects are commonly a result of rapid precipitation. Another contributing piece of evidence is the difference in particle size distributions observed between limestone- and lime-derived sulfite forms. The much wider distribution of crystal sizes seen in samples consisting of single plates indicates continual crystal growth. The narrower distribution of sizes seen among the spherical aggregates infers a more rapid initial growth within this same sampling interval with growth having been terminated at the maximum size permissible in the scrubbing system.

Special attention may be given to Figure 6F in which the aggregates are seen to consist of much smaller, more densely inter-penetrating plates than observed in other samples in this study. Although the exact cause of this differentiation is unknown, it should be noted that the level of the chloride ion in the scrubbing liquor is much higher for the time at which this sample was taken (2.13 percent by weight) than for any other sample studied in this system.

In lime systems, no definite relationship was seen between aggregate size or complexity and either chemical composition or physical/chemical operating conditions. In attempts to determine such a relationship, factors such as stoichiometric ratio, pH, slurry temperature, hold tank residence time, make/pass, L/G, weight percent of Mg^{++} or Cl^{-} in the liquor, and the presence or absence of fly ash were studied.

When limestone is used as the absorbent, the average size of the plate crystals formed in this environment appears to be inversely related to system stoichiometry, as shown in Figures 7A through 7F. The micrographs show a steadily decreasing average crystallite size with increasing Ca:S ratio. While no precise mathematical relationship has been derived, this observation argues in favor of stoichiometries approaching 1.0 in order to promote faster slurry filtration and clarification. Unfortunately, SO_2 removal efficiency suffers at such low stoichiometries.

Attempts also have been made to relate crystal morphology (in limestone operation) to factors such as pH, percent solid oxidation, slurry temperature, hold tank residence time, make/pass, L/G, and percent Cl^{-} or Mg^{++} in the liquor. No definite correlations have been seen. This failure to observe such relationships, here and in the lime systems discussed above, is viewed to be a result of inadequate or insufficient data rather than a lack of such relationships.

During the course of examination of samples received, a form of "mixed crystal" was observed occurring during the period January 1, 1976, to January 10, 1976, in both the TCA and venturi/spray tower systems and is shown in Figures 8 and 9. The usual appearance of the mixed crystal is that shown in Figures 8A, 8C, 9A, and 9B where a sulfite rosette appears in intimate physical association with a well-developed, although often imperfect, gypsum crystal. The gypsum crystals often show a large number of surface cracks and longitudinal crystal defects. Enlarged views of the areas of contact between the two forms show what appear to be $CaSO_3 \cdot 0.5H_2O$ plate crystals growing from the body of the gypsum prism. Figure 8B is such an enlargement of a contact zone of the form shown in 8A; note also arrows in Figures 8D, 9C, and 9D. Occurrence of these "mixed crystals" rarely has been observed in samples other than those included in the time period quoted above and in these samples only in minor (less than 5 percent) quantities. These forms may be related to the gypsum-calcium sulfite hemihydrate solid solutions discussed by Borgwardt.[1] Comparison of sample chemical composition and scrubber operating data for the period of time during which these samples were taken indicates no excursions from normal values which might be helpful in explaining the sudden appearance of these mixed forms. A possible explanation for the occurrence of the "mixed" forms is that the severe chemical, pH, and thermal gradients present in a scrubbing system provide an excellent environment for the precipitation of disordered, nonequilibrium crystals. Particularly under conditions of rapid precipitation and growth, crystals are easily formed having incorporated within their lattice ions which "do not belong" due to either stoichiometric or radius ratio effects ($SO_3^{=}$ inclusions in a $CaSO_4 \cdot 2H_2O$ lattice, for example). As a result of internal electrostatic forces, these "foreign" ions will tend to migrate through the parent crystal

these "foreign" ions will tend to migrate through the parent crystal lattice and, through a process of electrostatic segregation, form locally stable domains. When these domains are on the surface of a crystal, changes in the liquor chemistry and temperature surrounding the parent crystal can cause this originally small domain to grow outward in the form of another, but related, chemical compound through natural processes of precipitation and, where useful, dissolution of the parent crystal.

The occurrence of this process of exsolution and subsequent crystal growth on nucleation sites provided by surface domains is strongly suggested by the contact surfaces shown in Figures 8B, 9C, and 9D.

Morphology of Accessory Components

Under the general heading "accessory components" are included those materials which either are not directly involved in the desulfurization reaction or are present in such small quantities that their presence does not affect bulk sludge properties.

Fly ash is the most important of the accessory components in sludge samples obtained in this study from normal operations, compromising 20 to 40 percent by weight of the solids composition. It is normally present in the form of featureless spheres ranging in diameter from submicron sizes up to those greater than 150 microns. The spheres may be solid or hollow and consist of an amorphous aluminosilicate material usually containing calcium and/or iron. A portion of the fly ash is magnetic and ranges in quantity from 5 to 60 percent by weight. The presence of fly ash should exert some influence on liquor chemistry; samples of fly ash studied by other laboratories have shown neutralizing values of up to 4 meq/g.[7,8] A small fraction of the fly ash constituent is not spherical but appears as irregularly shaped vesicular particles. Occasionally $CaSO_3 \cdot 0.5H_2O$ plate crystals will be observed to have been precipitated on the surface of fly ash spheres.

Gypsum (in unoxidized systems) and unreacted absorbent are generally observed in very small quantities (less than 5 percent total by weight). The $CaSO_4 \cdot 2H_2O$ occurs primarily as broken and partially decomposed prisms (left center, Figure 3C) or as twinned forms (Figure 5B). Unreacted absorbent will be seen as partially or almost completely dissolved irregular forms (right center, Figure 5A and bottom center, Figure 7B). Unburned coal and quartz are sometimes present in small amounts.

Morphology of Solids Formed Under Forced Oxidation

During the first quarter, 1977, forced oxidation tests were conducted by installation of an air sparger and accessory reaction tanks in the venturi scrubbing train. The results of this modification may be seen in Figure 10 in which micrographs of solids from analysis points 1816 (spray tower hold tank, no oxidation) and 1815 (venturi reaction tank, oxidation) are shown for comparison. Where forced oxidation has been used (Figures 8B, 8D, and 8F), the primary reaction product appears as large, blocky

gypsum crystals as compared to the much smaller single plates and open-form aggregates (Figures 8A, 8C, and 8E) typical of routine limestone operation. The $CaSO_4 \cdot 2H_2O$ crystals formed in this mode of oxidation are often broken and twined, and range in size from 10 to greater than 100 microns. Accompanying forms of $CaSO_3 \cdot 0.5H_2O$ are not observed.

Accessory components of sludge produced in forced oxidation tests are equivalent to those found under routine operation.

Section 5

SLURRY SETTLING BEHAVIOR

The settling behavior of slurries received during this study has been determined by a static method. The samples, approximately 1 liter in volume, are transferred to 1-liter graduated cylinders (inside diameter of 6 cm and with a depth of 42 cm), mixed thoroughly by stirring and repeated inversion of the cylinders, and then allowed to settle. The height of the solids-liquid interface is tabulated and plotted as a function of time. The settled bulk density is calculated from Equation 1.

$$\rho_{sb} = \frac{(B-A) - D(C-E)}{E} \qquad (1)$$

where:

ρ_{sb} = settled bulk density, g/mL
A = weight of empty cylinder, g
B = weight of cylinder + slurry, g
C = initial volume of slurry, cm^3
D = density of resulting supernatant fluid (after settling), g/cm^3
E = volume of settled slurry, cm^3

The density measurement, D, was initially determined by liquid pycnometer measurements of aliquots taken from various levels within the supernatant liquor. The results indicated that no detectable density gradient existed within the liquid; therefore, all subsequent density measurements were made with a hydrometer calibrated over the range 1.000 to 1.2000 $g \cdot cm^{-3}$. The settled percent solids are calculated from Equation 2.

$$\text{settled solids, \%} = \frac{(\text{\% solids in initial slurry}) \times (\text{total wt. of slurry sample})}{(\text{weight of settled slurry})} \qquad (2)$$

The weight of the settled slurry, including entrapped liquor, is obtained by subtracting the weight of the supernatant liquor (obtained by density and volume measurements) from the total weight of the slurry sample.

Sludge settling rates are known to be a function of temperature, increasing temperature causing an increase in settling rate. However, because of temperature gradients existing within the scrubber process train and seasonal variations in clarifier temperatures, all settling tests in this study were performed at room temperature.

The sedimentation behavior of particulate (nonflocculant) slurries may be described generally by three basic modes: clarification, zone settling, and compression; with clarification applying at low solids concentration and compression applying at very high percent solids. In the clarification mode, individual particles settle independently at constant rates which are primarily dependent on particle size and shape (Stokes'

Law applies). Considerable particle size classification occurs with the larger particles settling first and the smallest settling last. In the zone settling mode, the particles are conceived to be all locked into a plastic structure with very little independent settling (results from higher percent solids). Here, the solids subside as a consolidated structure so that ideally a single settling rate may be ascribed to all particles; this settling rate will be a function of solids concentration although individual particle morphology may play a part because of its effect in determining the degree of porosity of the consolidated structure. Ultimately, with very high solids concentration or towards the end of any static settling test, the regime of compression settling will be reached. In this mode, the hydrostatic bearing capacity of the settled solids, including entrapped liquor, is assumed to be approximately equal to the load produced by the settled solids plus any overlaying liquid. Under these conditions, subsequent subsidence will occur primarily through the formation of dewatering channels or the rake action at the bottom of a clarifier.

Under average conditions in this study (limiting cylinder diameter, static settling, 12 to 25 percent solids in slurry), zone settling most often applied in that there was very little particle size or shape classification during settling; i.e., the entire body of solids settles simultaneously by dewatering. There was very little free particle settling. Rather, all particles settle together, their combined weight gradually forcing the water contained within the slurry past them to the top of the interface. As the settling slurry approaches the compression stage, "dewatering channels" were seen in cross section through the glass cylinder walls. These channels gave the appearance of dendritic or tree-like structures arising from many small channels at a depth of 7 to 8 cm. beneath the interface and graually coalescing into a single channel which allowed the water to escape from the settling solids.

As slurry solids content decreases below 10 percent, clarification-type settling is seen and individual particles settle according to their own size and weight. The average settling rate is very rapid (2 to 10 times faster than with slurries containing 15 to 25 percent solids), and the solids-liquid interface is quite indistinct, often definable only after compression settling is approached.

Settling rates for solids of similar particulate morphology are generally dependent on solids concentration. Slurries with high solids concentrations settle more slowly. This may be illustrated with reference to Figure 11A in which the settling rates for some limestone slurries are shown by a plot of interface position as a function of time. Individual curves are labelled for sample identification and original slurry percent solids. Thicker (higher solids concentration) slurries have lower settling rates and take longer to reach the compression stage. Slurry settling rate behavior is complicated by the fact that the solids component morphology can exert a strong influence. As an example of this effect, behavior of slurries obtained from the TCA system on May 14, 1976, and April 12, 1976, (Figure 11B) may be compared. Although the solids content by weight in both slurries are essentially the same, the April sample settles more than three times as fast and attains, when settled to compaction, an ultimate solids content of 68 percent compared to 38 percent for the May sample.

Inspection of the micrographs of these solids (Figure 12) reveals that while both contain a predominance of single plates, the May sample consists primarily of very small plates and plate fragments. These smaller particles inhibit settling and entrap more liquor upon reaching the compression stage due to a higher degree of inter-particle contact and sample surface area. This in turn limits the amoung of liquor that may flow past particles during settling and increases the difficulty with which dewatering can occur upon reaching the compression stage.

The general relationship between sludge settling rate and percent solids for all samples included in this study is shown in Figure 13. To illustrate the differences in settling rates caused by solids morphology, lime slurries (spherical aggregates) are indicated by the character "o," limestone slurries (plates) by a "□," and slurries obtained during forced oxidation tests (blocky gypsum crystals) by an "x." In the range 10 to 25 percent solids, both lime- and limestone-derived slurries show essentially the same linear, inverse relationship to settling rate. On entering the regime of clarification settling, however, the behavior of the two types of slurries differs. The hydrodynamically preferable spherical forms precipitated with lime scrubbing demonstrate more rapid size classification and less hydrodynamic drag during settling than do the plates or open aggregates of limestone operation and, therefore, show a more rapid increase in settling rate within the same range of solids content. The gypsum slurries produced under conditions of forced oxidation settle at the noticeably faster (5 to 10 times) rate than the other slurries even though the slurry solids content enforces zone settling. The crystals' very large size forms a settling structure which is relatively open to water and thus allows less hindered settling although independent settling of particles will not be allowed. The greater degree to which these slurries may be dewatered is reflected in the observation that the slurry produced with no oxidation settles to a final solids content of 23 percent with a bulk density of 1.17, while the gypsum slurry settles in a much shorter time to a final 61 percent solids and bulk density of 1.55.

Figure 14 shows the relationship between the bulk density of the settled slurries and their settled solids content. An approximately linear, positive relationship is seen between these two properties. Lime and limestone slurries show essentially the same behavior.

Fly ash-free test runs on both the TCA and venturi/spray tower systems during this study provided data on slurry properties which may be compared with that derived from normal operations. Based on these data, the absence of fly ash has not clearly shown any effect on sludge property relationships as shown in Figures 13 and 14. In Figure 15 are shown the frequency distributions for the values obtained for the settled solids content of lime and limestone slurries and for all slurries taken from fly ash-free (<10 percent ash) runs. While both lime- and limestone-derived slurries exhibit essentially the same behavior, the slurries containing no fly ash seem to settle to a slightly lower final solids content.

Due to sample handling and shipping, the static settling tests performed at Muscle Shoals were conducted from 3 to 14 days after the samples were taken from the process loop. Settling tests conducted at the Shawnee

Test Facility, however, are generally performed within a short time after acquisition. In addition, settling data at Shawnee are generated by the Dorr-Oliver method which differs from a static test in that the bottom of the test cylinder contains a rake rotated at 1/6 rpm during the test. In order to compare data generated by the two methods and to evaluate possible effects caused by the delay in testing, a program of comparison tests was conducted. The results of this work are contained in Table 3. The mean value of the difference in the two measurements, $\bar{y}$, is 3.6 with a standard deviation of 10.8; the standard error of $\bar{y}$ is $10.8/\sqrt{26}$ or 2.12. The t-distribution value for 25 degrees of freedom and 95 percent double-sized confidence limit is 2.06, so the limits are $3.6 \pm 2.06 \times 2.12$ or 7.96 to -0.76. Based on this information, no bias is conclusively shown between the two procedures.

Section 6

SOLIDS SURFACE AREA MEASUREMENTS

The size, shape, and complexity of individual solid particles in the scrubbing slurry are important in that these factors may influence or control processes such as chemical reaction, filtration, or dewatering rates. An indirect indication of the average particle size and complexity of the slurry solids is available in measurements of the solids surface area. The equipment and methodology necessary to perform this measurement have been developed and implemented for routine characterization of dried scrubber solids. The specific instrumental technique used is a nitrogen desorption method based on a variation of the single point B.E.T. method and is adequately described in the literature.[2]

Previously dried samples are placed in glass U-tubes approximately 10 cm in length and swept for 1 hour with a purge gas (30 percent nitrogen in helium) at a rate of 80 $ml \cdot min^{-1}$, after which analysis is performed on the sample without removing it from the tube. Values for the surface area (M^2/g) of samples received during this period are reported in Tables 1 and 2. This method yields a precision of better than 1 percent and an accuracy of better than 5 percent.

Figure 16 shows the frequency distribution of surface area values. The solid lines show the results of all measurements, while the dashed lines indicate measurements made under "fly ash-free" (ash <10 percent) conditions. Note that the average specific area for samples obtained during lime scrubbing is greater than that measured for samples taken from systems employing limestone. This difference in surface area values reflects the differences in average particle size and morphology in lime and limestone slurries and correlates with the observation that lime slurries are more difficult to dewater than limestone slurries.

The frequency distribution of surface area values for fly ash-free runs shows essentially the same form as displayed by all runs combined. This indicates that the surface area component contributed by the fly ash is not a critical factor in determining sludge characteristics.

Section 7

THERMAL ANALYSIS OF SCRUBBER SOLIDS

Thermal analysis of selected dried scrubbing solids was employed using differential scanning calorimetry (DSC) in the range 330° to 500°C. This temperature range was selected in order to study the thermal dehydration of the $CaSO_3 \cdot 0.5H_2O$ component. It was felt that substitution of carbonate or sulfate into the sulfite structure would result either in a shift of this compound's desolvation temperature away from the observed in the pure state or in an increase in complexity of the normally straightforward endothermic desolvation reaction. All samples studied were analyzed using a Perkin-Elmer DSC-2 differential scanning calorimeter. The temperature scan rate used was 10°C/min, and dry nitrogen at a rate of 20 mL/min was used as the purge gas. Prior thermal conditioning consisted of preheating the samples (in the instrument) at a temperature of 330°C for a period of 15 min. All samples were analyzed in nonvolatile sample pans (small aluminum containers of approximately 0.25-in. diameter and 0.125-in. depth, with aluminum cover discs lightly crimped in place to prevent sample loss but not hermetically sealed).

Two types of thermal activity were observed. The type of behavior illustrated in Figure 17A has been observed to predominate in samples taken from lime-scrubber systems. Here a generally straight-forward endothermic desolvation of the sulfite occurs only after an initial reaction which may represent a gradual desolvation or decomposition of an unknown compound.

Figure 17B shows a type of thermal activity which is representative of limestone systems. In this case no initial thermal activity is seen, but the endothermic reaction attributed to the sulfite decomposition clearly consists of at least two components, although inadequately resolved. The dashed curve superimposed on Figure 17B shows the thermogram produced by the thermal decomposition of pure $CaSO_3 \cdot 0.5H_2O$ prepared in our laboratory.

Thermal analysis of lime/limestones scrubbing materials has been reported previously.[3] In these studies, synthetic scrubbing solids were prepared by the addition of fly ash to mixtures of the pure components normally found in such sludges ($CaSO_3 \cdot 0.5H_2O$, $CaSO_4 \cdot 2H_2O$, $CaCO_3$, etc.) These mixtures were studies by differential thermal analysis (DTA) and thermogravimetric analysis (TGA). The $CaSO_3 \cdot 0.5H_2O$ was found to undergo dehydration in the region 350° to 410°C. This compares favorably with our results which indicate an average decomposition temperature of approximately 390°C. These values represent a deviation from the dehydration temperature of 367°C for the pure compound as reported by Schröpfer[4] utilizing DTA. DSC investigation of the pure compound prepared in TVA's laboratory indicates a decomposition temperature of 364°C.

It is not clear which aspects of the complex thermal behavior of the samples examined to date are a result of matrix effects and which may be assigned to reactions of carbonate- or sulfate-substituted $CaSO_3 \cdot 0.5H_2O$ species. An attempt was made to clarify this situation by using

H_2O-saturated N_2 as the purge gas. Ideally an increase in the partial pressure of H_2O in the gas environment surrounding the sample should have displaced the dehydration temperature of $CaSO_3 \cdot 0.5H_2O$. This effect was not observed due to instrument noise caused by microdroplets of water in the gas stream.

The primary purpose of this study was to show any relationship between the dehydration temperature of $CaSO_3 \cdot 0.5H_2O$ and other indicators of structure perturbation (optical index of refraction, length of crystallographic unit cell axes as determined by x-ray diffraction, etc.). Thermal analysis of 57 samples did not show any definite relationship between the desolvation temperature of the hemihydrate and any other indicator of crystal structure perturbation. The reason for apparent failure to show any defined relationship is attributed to lack of adequate precision in both thermal and crystallographic data, although the former is likely to play the major role. Data obtained from these experiments are shown in Table 4.

As an offshoot of this work, a simple and rapid method for determination of $CaSO_4 \cdot 2H_2O$ in scrubber solids was developed. It was shown that the peak area resulting from gypsum dehydration is directly and linearly proportional to the percent of gypsum in the sample[5,6] (in DSC, peak area is proportional to the ΔH of reaction). This peak is not obscured or interfered with by other components in the sample matrices studied and thus provides a clear-cut distinction between gypsum $SO_4^=$ and substituted $SO_4^=$ within the sample. Over the range 10 to 0.3 percent gypsum, determinations may be made with a precision of better than 5 percent and an accuracy of better than 5 percent.

Calibration standards over the range 0.06 to 10 percent were prepared by adding pure gypsum to a matrix prepared by batch heating a selected dried scrubbing sludge (original composition: 35 percent ash, 12 percent $CaCO_3$, 42 percent $CaSO_3 \cdot 0.5H_2O$, and 10 percent gypsum) at a temperature of 200°C for 24 hours. Examination of this reference matrix by infrared, x-ray diffraction, DSC, and optical microscopy after heating revealed no trace of residual gypsum. Samples of scrubber solids to be analyzed were dried at a temperature of 50°C (in the instrument) to a constant baseline to remove surface-adsorbed H_2O. The previously prepared inert (over the temperature range of interest) matrix was used as a reference material. A temperature scan rate of 10°C/min was used for both samples and unknowns. Samples of known materials were prepared by adding known, weighed amounts of $CaSO_4 \cdot 2H_2O$ to dried sludge samples which had been found by x-ray, IR, and DSC to contain no gypsum. These samples were analyzed and compared to the previously prepared calibration curve. Results of this investigation are in Table 5. While this procedure is fairly accurate over the range 10 to 0.5 percent (weight) gypsum, inaccuracy due to difficulties in preparing solid mixtures at these levels increases quickly below 0.5 percent. The method is easily extended to gypsum contents higher than 10 percent, although an inert diluent may be necessary above 20 percent gypsum.

Section 8

STATISTICAL ANALYSIS

The statistical analysis of sludge data from the venturi/spray tower and TCA systems centered on determining typical operating conditions for the duration of the data and an examination of extreme results (both high and low) of settled bulk density, percent settled solids, and their associated variables. These variables were then examined for possible causitive effects on settled bulk density and percent settled solids. Estimates of variation with regard to both typical and extreme operating conditions were made so significant changes in the response of settled bulk density and percent settled solids could be identified. Nonlinear regression models were developed which characterized the behavior of settled bulk density and the percentage of settled solids. Summary tables (6 to 10) are presented for average and extreme values for all variables.

In the presentation of these analyses, the total calcium content of the sludge (that which is bonded to sulfite, sulfate, and carbonate) is reported as CaO. Also SO_2, SO_3, and CO_2 represent the relative quantities of sulfite, sulfate, and carbonate in the sludge.

Mean Values

Mean values and standard deviations are presented in Table 6 for both the lime and limestone product sludges studied over the test period. Identification of high and low ranges of the variables are also presented. For the lime product sludges, the following averages were seen: oxidation, 20 percent; settled solids, 43 percent by weight; settled bulk density, 1.3 g/cc; and 10 percent solids recirculated. The solids, by weight, had an average composition of 32 percent fly ash, 29 percent CaO, 25 percent sulfite, 7 percent sulfate, and 1.5 percent carbonate. Averages of the limestone product sludge data show 22 percent oxidation, 41 percent settled solids, 1.3 g/cc settled bulk density, and 15 percent solids recirculated. The average solids analysis is 33 percent fly ash, 30 percent CaO, 21 percent sulfite, 6 percent sulfate, and 5.5 percent carbonate.

Percent Settled Solids

The following mean values were associated with high levels (57.9 percent) of settled solids for the lime product sludges: high natural oxidation, 38.6 percent; high percentage of solids recirculated, 14.5 percent; high fly ash content, 39.5 percent; and low levels of calcium sulfite solids, 18.6 percent. Two samples under a program for forced oxidation had oxidation in excess of 95 percent. This was with an average of 18.6 percent solids recirculated, 55.7 percent fly ash, 0.5 percent sulfite solids, and 65 percent settled solids.

The limestone product sludges also had two groups of data with high levels of settled solids. One group had an average oxidation of 17.9 percent. This group was characterized by 17.7 percent solids recirculated,

a fly ash content of 38.6 percent, and settled solids of 53.2 percent. The second group obtained during forced oxidation testing had an average oxidation of 98.3 percent with settled solids of 63.3 percent, fly ash content of 64.5 percent, and extremely low sulfite solids of 0.2 percent. Table 7 summarizes the data characteristic of high settled solids.

Low levels of settled solids were also examined for the lime and limestone product sludges to obtain further information on the behavior and effects of variables associated with the percent of settled solids. The lime product sludges had an average of 26.9 percent settled solids with mean oxidation of 14.8 percent, 8.8 percent solids recirculated, fly ash content of 17.0 percent, and a high level of sulfite solids of 25.2 percent. Also at high levels were CaO at 37.5 percent and carbonate at 2.8 percent.

The limestone product sludges exhibited similar behavior at low levels of settled solids. An average of 26.9 percent settled solids was associated with 15.6 percent oxidation, 9.2 percent solids recirculated, and a fly ash content of 14.0 percent. The solids were composed of 27.2 percent sulfite, 38.8 percent CaO, and 7.2 percent carbonate. Table 8 summarizes the low settled solids characteristics.

Settled Bulk Density

Analysis of factors associated with settled bulk density indicated the effect of high oxidation versus low oxidation levels. In general, for the lime product sludges, a settled bulk density of 1.4 g/cc or more was regarded as a "high" level.

The following were average values associated with low levels of oxidation (11.4 percent average): settled bulk density, 1.43 g/cc; percent recirculated solids, 7.6 percent; fly ash, 34.3 percent; CaO, 28.8 percent; sulfite, 25.2 percent; and carbonate, 3.2 percent. For the high oxidation group with a mean oxidation of 96.6 percent, the associated values were: fly ash, 55.7 percent; percent solids recirculated, 18.6 percent; sulfite, 0.5 percent; carbonate, 0.3 percent; and CaO, 15.6 percent. For this high oxidation group, the settled bulk density was 1.65 g/cc.

Settled bulk density for the limestone product sludges behaved similarly. An average settled bulk density of 1.43 g/cc was associated with an oxidation level of 11.4 percent. Typical average values for the other variables were: percent solids recirculated, 15.2 percent; fly ash, 32.4 percent; CaO, 30.5 percent; sulfite content, 24.1 percent; and carbonate content, 4.8 percent. The settled bulk density for the high oxidation group was 1.61 g/cc with an average oxidation value of 98.3 percent. The other average values were: fly ash, 64.5 percent; CaO, 12 percent; sulfite, 0.2 percent; carbonate, 0.7 percent; and 16.4 percent solids recirculated. Table 9 summarizes the high settled bulk density data.

In general, the lower settled bulk density for both lime and limestone systems was associated with low oxidation, low fly ash content, and a lower than average percent solids recirculated. At the same time high levels

of CaO, sulfite, and carbonate solids occurred. Table 10 illustrates the low settled bulk density data.

Relationships Found in the Data Using Regression Analysis

The data were extensively examined for relationships between the percentage of settled solids and settled bulk density and those variables which determine their behavior. The two variables having the largest effect on both settled solids and settled bulk density are the percent sulfite solids and percent solids recirculated. The analysis resulted in equations which quantify the response of settled solids and settled bulk density to changes in the percent sulfite solids and percent solids recirculated. It must be noted that these equations pertain only to the ranges of data which occurred in this study. The Equations are:

$$\text{Lime: } \%\text{ settled solids} = 39.6\ X_1^{-0.09}\ X_2^{0.15} \quad (3)$$

$$\rho_{sb} = 1.5\ X_1^{-0.05}\ X_2^{0.01} \quad (4)$$

$$\text{Limestone: } \%\text{ settled solids} = 17.1\ X_1^{-0.09}\ X_2^{0.42} \quad (5)$$

$$\rho_{sb} = 1.15\ X_1^{-0.04}\ X_2^{0.09} \quad (6)$$

where: ρ_{sb} = settled bulk density, g/mL
X_1 = wt. % sulfite solids
X_2 = wt. % solids recirculated

As an example, Equation 5 for limestone product sludges predicts an average of 40.9 percent settled solids for 21 percent sulfite solids and 15 percent solids recirculated.

$$\%\text{ settled solids} = 17.1(21.0)^{-0.09}(15.0)^{0.42}$$

$$\ln(\%\text{ settled solids}) = \ln(17.1) - 0.09\ \ln(21.0) + 0.42\ \ln(15.0)$$

$$= 2.84 - 0.27 + 1.14 = 3.71$$

$$\%\text{ settled solids} = \exp(3.71) = 40.9\%$$

Table 6 indicates that this is a typical settled solids figure. Table 11 summarizes the change in settled bulk density and percent settled solids for changes in percent sulfite solids and percent solids recirculated, using Equations 5 and 6.

For a constant percent solids recirculated, raising the sulfite content of the sludge decreases both settled solids and settled bulk density. For a constant sulfite content, raising the percent solids recirculated raises both the percent settled solids and settled bulk density. The last two entries in Table 6 illustrate the response of settled solids and settled bulk density to a combination of (1) low sulfite solids (0.4 percent) and high solids recirculated (18.0 percent) and (2) a high sulfite solids (37.0 percent) and low solids recirculated (5.0 percent). The low

sulfite solids with high solids recirculated results in a predicted high settled bulk density of 1.61 g/cc and high settled solids of 62.5 percent. These predicted values correspond well to actual values of 1.65 g/cc and 62.8 percent which occurred at 0.4 percent sulfite solids and 17.8 percent or 18.2 percent solids recirculated, respectively. The case of high sulfite solids and low solids recirculated indicates a low estimated settled bulk density of 1.20 g/cc and low settled solids of 24.3 percent. Actually, a 1.16 g/cc settled bulk density occurred at 36.3 percent sulfite solids and 7.5 percent solids recirculated, while 24.9 percent settled solids was noted at 36.6 percent sulfite solids and 7.6 percent solids recirculated. The equations are seen to typify the behavior found in the data. Similar calculations can be made for the lime system.

A more detailed explanation of the derivation of the equations and the statistical analysis are presented in the next section.

Regression Models - Statistical Considerations

The behavior of the percentage of settled solids and settled bulk density was further characterized by examining possible relationships with associated variables. A nonlinear model best described the response of settled solids and settled bulk density with the percentage of solids recirculated and calcium sulfite content of the solids being the independent variables. The model is:

$$y = \alpha X_1^{B_1} X_2^{B_2} \varepsilon \qquad (7)$$

where Y is the dependent variable of percent settled solids or settled bulk density, X_1 is the percent of sulfite solids and X_2 is the percent of solids recirculated. The unknown parameters to be estimated are α, B_1, B_2, with ε being a random error. The model can be linearized by taking natural logarithms which result in the following equation:

$$\ln Y = \ln\alpha + B_1 \ln X_1 + B_2 \ln X_2 + \ln\varepsilon \qquad (8)$$

which can be estimated by standard least squares analysis. For valid tests of significance and confidence intervals, $\ln\varepsilon$ must be $N(0, I\sigma^2)$. Table 11 presents the estimates $\ln\alpha$, b_1, and b_2 of $\ln\alpha$, B_1, and B_2 with the associated standard errors. Extensive examination of the residuals did not indicate any model definciencies or violations of standard assumptions necessary for least squares analysis.

The resulting models are given by Equations 3, 4, 5, and 6 which are shown on page 19.

One indication of how well an equation fits the data is the multiple correlation coefficient squared (R^2). It estimates the proportion of total variation explained by the regression. The F-value indicates how significant, in a statistical sense, the coefficients are when taken all together. Table 13 summarizes the R^2 and F values from the regression analysis plus the antilogarithm of the standard error of estimates.

Figures 18 through 29 show the graphs of observed values versus predicted values from the nonlinear models. (For both limestone and lime and the dependent variables of percent settled solids and settled bulk density). Three types of graphs are plotted: (1) dependent variable versus percent calcium sulfite solids, (2) dependent variable versus percent solids recirculated, and (3) observed dependent variable versus the predicted dependent variable at the same values of the independent variables.

For example, Figures 18, 19, and 20 for limestone show how the percent settled solids decline as a function of percent calcium sulfite solids and increases as a function of percent solids recirculated, and that the regression equation does fairly well in predicting the response of percent settled solids. Examination of the other figures indicates that the regression equations model the data well for the limestone system, but not quite as well for the lime system.

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8. Martens, D. C., M. G. Schnappinger, and L. W. Zelazny, "The Plant Availability of Potassium in Fly Ash," Soil Science Society of America Proceedings, 34, 453-456 (1970).

FIGURE 1

Photomicrographs illustrating various forms in which $CaSO_3 \cdot 0.5H_2O$ is found in scrubber sludge.

A. Typical well-formed single sulfite plates formed when limestone is used as the absorbent

B. Typical well-formed single sulfite plates formed when limestone is used as the absorbent

C. Open form of aggregate sulfite crystal formed when limestone is used as the absorbent

D. Aggregated form of sulfite crystal (rosette) formed when limestone is used as the absorbent

E. Typical spherical aggregates of sulfite crystals formed when lime is used as the absorbent

F. Typical spherical aggregates of sulfite crystals formed when lime is used as the absorbent

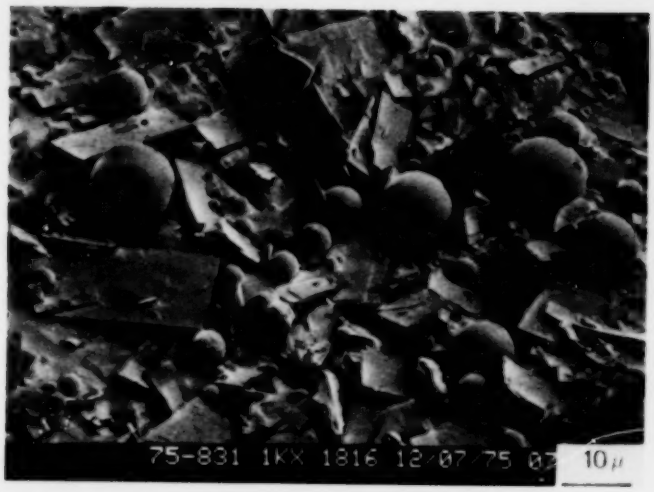

Figure 1A

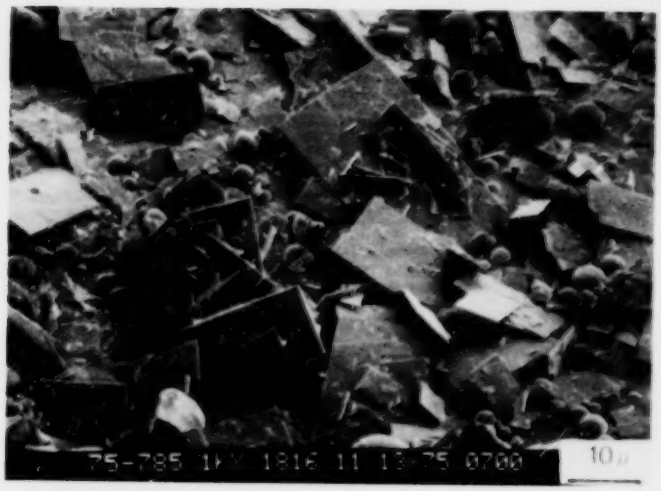

Figure 1B

Figure 1C

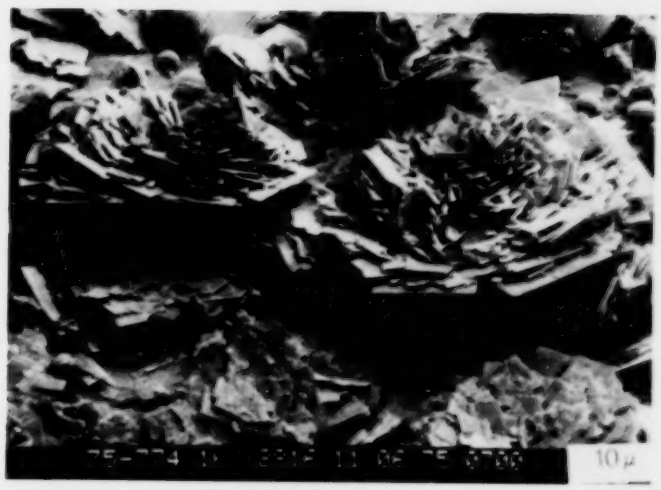

Figure 1D

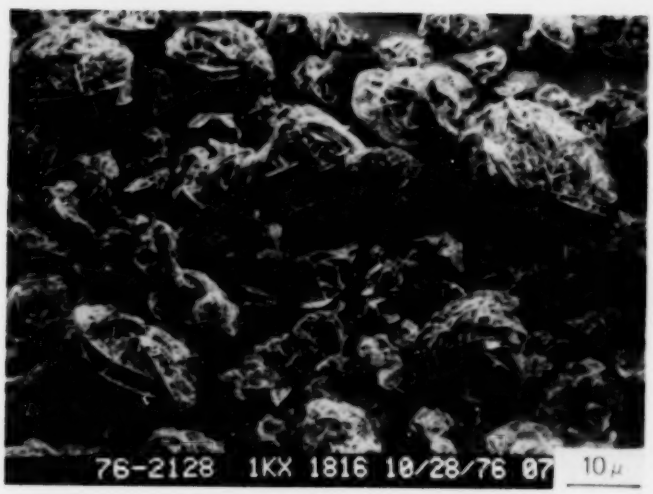

Figure 1E

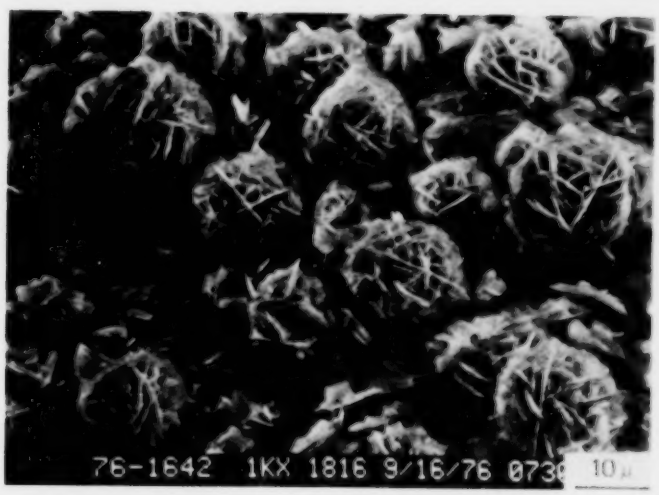

Figure 1F

FIGURE 2

Photomicrographs of $CaSO_3 \cdot 0.5H_2O$ aggregates formed when lime is used as the absorbent.

A. Spherical sulfite aggregates formed when using lime as the absorbent on 4/11/75

B. Spherical sulfite aggregates formed when using lime as the absorbent on 4/11/75

C. Spherical sulfite aggregates formed when using lime as the absorbent on 9/28/75

D. Spherical sulfite aggregates formed when using lime as the absorbent on 9/21/75

E. Spherical sulfite aggregates formed when using lime as the absorbent on 10/5/75

F. Spherical sulfite aggregates fomred when using lime as the absorben on 9/28/75

Figure 2A

Figure 2B

Figure 2C

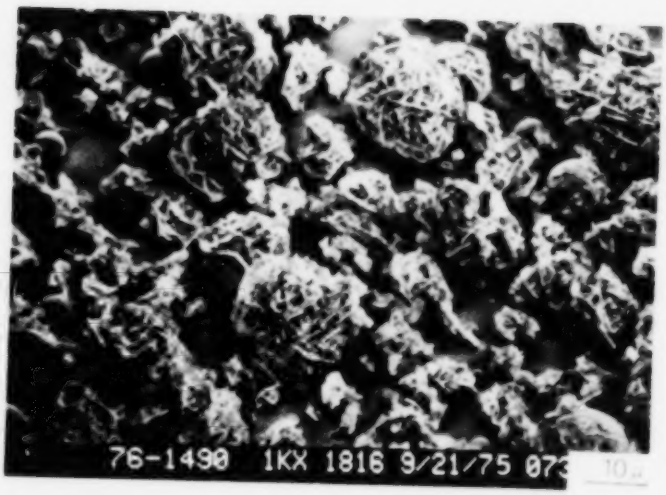

Figure 2D

Figure 2E

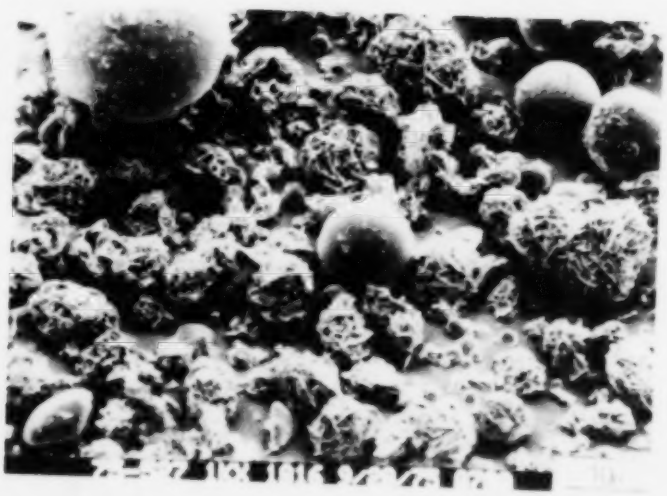

Figure 2F

FIGURE 3

Photomicrographs of $CaSO_3 \cdot 0.5H_2O$ plates formed when limestone is used as the absorbent.

A. Flat sulfite plates formed when using limestone as the absorbent on 10/21/75

B. Flat sulfite plates formed when using limestone as the absorbent on 10/12/75

C. Flat sulfite plates formed when using limestone as the absorbent on 11/6/75

D. Flat sulfite plates formed when using limestone as the absorbent on 10/28/75

E. Flat sulfite plates formed when using limestone as the absorbent on 11/19/75

F. Flat sulfite plates formed when using limestone as the absorbent on 11/19/75

Figure 3A

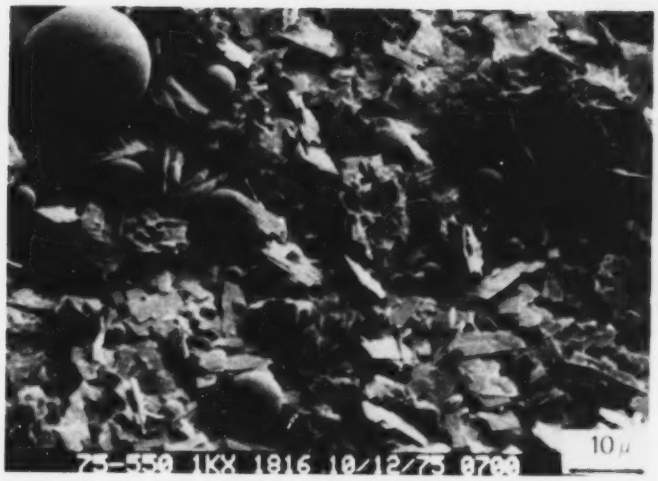

Figure 3B

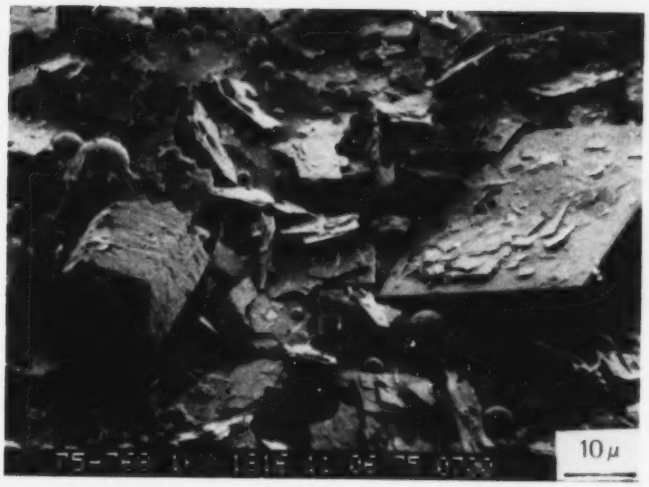

Figure 3C

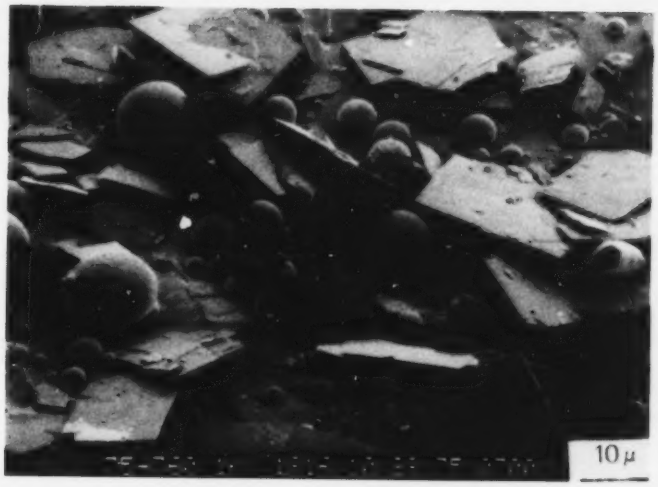

Figure 3D

Figure 3E

Figure 3F

FIGURE 4

Photomicrographs of $CaSO_3 \cdot 0.5H_2O$ aggregates formed when lime is used as the absorbent.

A. Spherical sulfite aggregates formed when using lime as the absorbent on 2/15/76

B. Spherical sulfite aggregates formed when using lime as the absorbent on 2/15/76

C. Spherical sulfite aggregates formed when using lime as the absorbent on 2/21/76

D. Spherical sulfite aggregates formed when using lime as the absorbent on 2/21/76

E. Spherical sulfite aggregates formed when using lime as the absorbent on 3/2/76

F. Spherical sulfite aggregates formed when using lime as the absorbent on 3/2/76

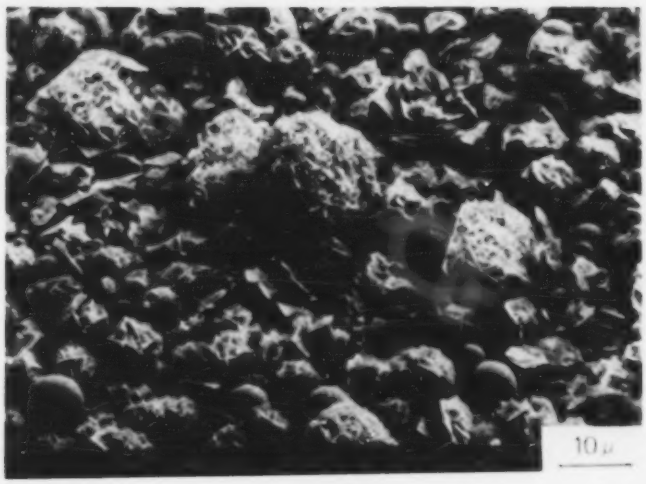

Figure 4A

Figure 4B

Figure 4C

Figure 4D

Figure 4E

Figure 4F

FIGURE 5

Photomicrographs of $CaSO_3 \cdot 0.5H_2O$ plates formed when limestone is used as the absorbent.

A. Flat sulfite plates formed when using limestone as the absorbent on 3/28/76 (note: unreacted absorbent--right center)

B. Flat sulfite plates formed when using limestone as the absorbent on 3/14/76 (note: twinned form of gypsum crystal--right center)

C. Flat sulfite plates formed when using limestone as the absorbent on 4/3/76

D. Flat sulfite plates formed when using limestone as the absorbent on 3/20/76

E. Flat sulfite plates formed when using limestone as the absorbent on 4/21/76

F. Flat sulfite plates formed when using limestone as the absorbent on 4/21/76

Figure 5A

Figure 5B

Figure 5C

Figure 5D

Figure 5E

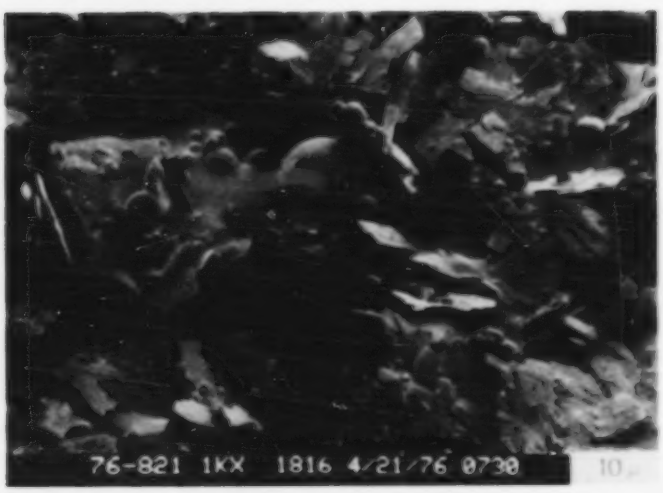

Figure 5F

FIGURE 6

Photomicrographs of $CaSO_3 \cdot 0.5H_2O$ aggregates formed when using lime as the absorbent.

A. Spherical sulfite aggregates formed when using lime as the absorbent on 5/15/76

B. Spherical sulfite aggregates formed when using lime as the absorbent on 5/8/76

C. Spherical sulfite aggregates formed when using lime as the absorbent on 6/9/76

D. Spherical sulfite aggregates formed when using lime as the absorbent on 5/31/76

E. Spherical sulfite aggregates formed when using lime as the absorbent on 6/27/76

F. Densely inter-penetrating (aggregates) sulfite plates formed under elevated levels of chloride ion (2.13 wt percent) when using lime as the absorbent on 6/20/76

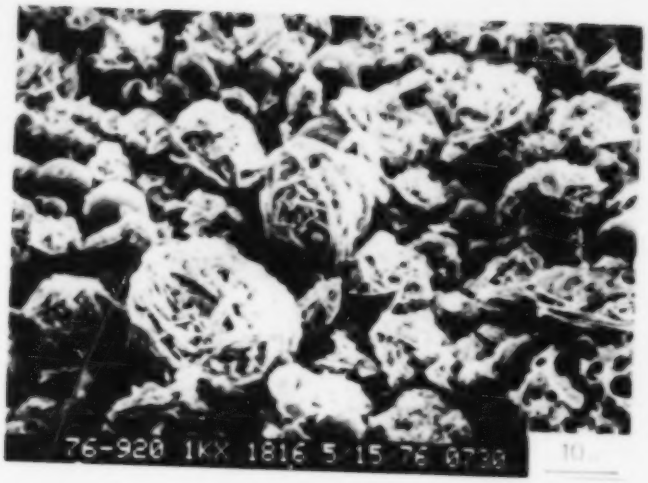

Figure 6A

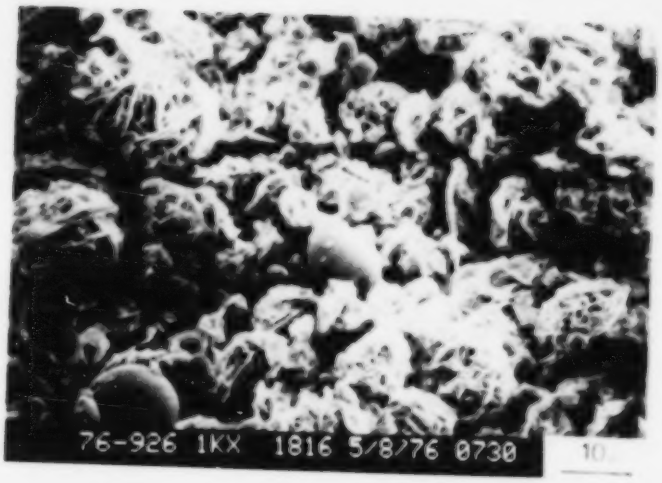

Figure 6B

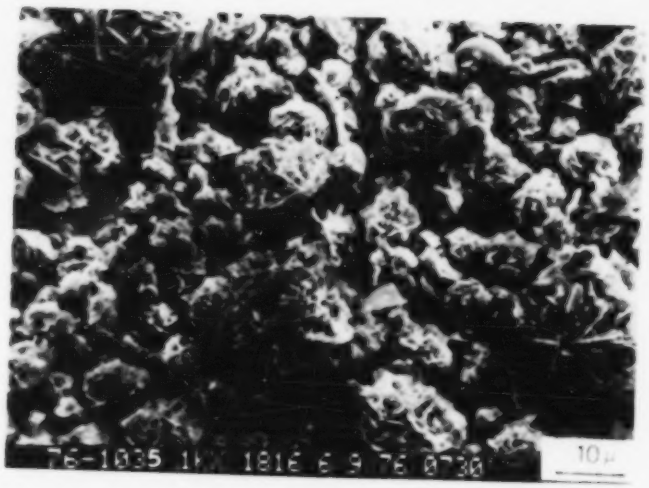

Figure 6C

Figure 6D

Figure 6E

Figure 6F

FIGURE 7

Photomicrographs illustrating the relationship between $CaSO_3 \cdot 0.5H_2O$ plate size and scrubber system Ca:S stoichiometry with limestone as the absorbent.

A. Flat sulfite plates formed when using a Ca:S stoichiometry of 0.98

B. Flat sulfite plates formed when using a Ca:S stoichiometry of 1.06

C. Flat sulfite plates formed when using a Ca:S stoichiometry of 1.13

D. Flat sulfite plates formed when using a Ca:S stoichiometry of 1.27

E. Flat sulfite plates formed when using a Ca:S stoichiometry of 1.43

F. Flat sulfite plates formed when using a Ca:S stoichiometry of 1.63

Figure 7A
Stoic.=0.98

Figure 7B
Stoic.=1.06

Figure 7C
Stoic.=1.13

Figure 7D
Stoic.-1.27

Figure 7E
Stoic.=1.43

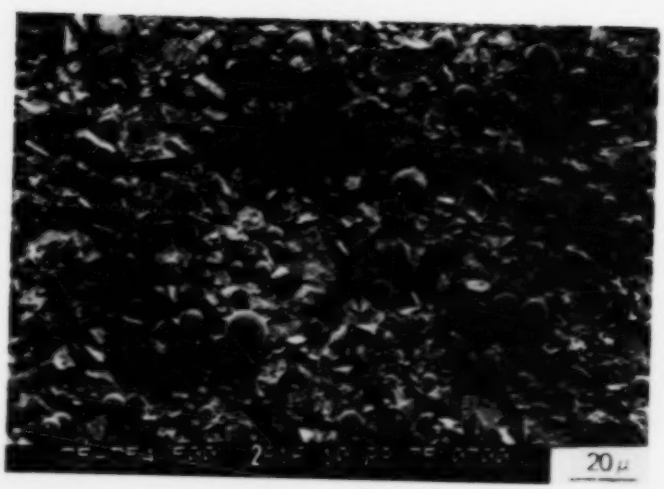

Figure 7F
Stoic.=1.63

FIGURE 8

Photomicrographs of "Mixed Crystal" forms.

A. Sulfite rosette in intimate physical association with a well-developed gypsum crystal

B. Enlargement of a contact zone of the sulfite rosette and gypsum crystal of the form shown in A

C. Sulfite rosette in intimate physical association with a gypsum crystal

D. Contact zone of sulfite and gypsum mixed crystal (note: arrow)

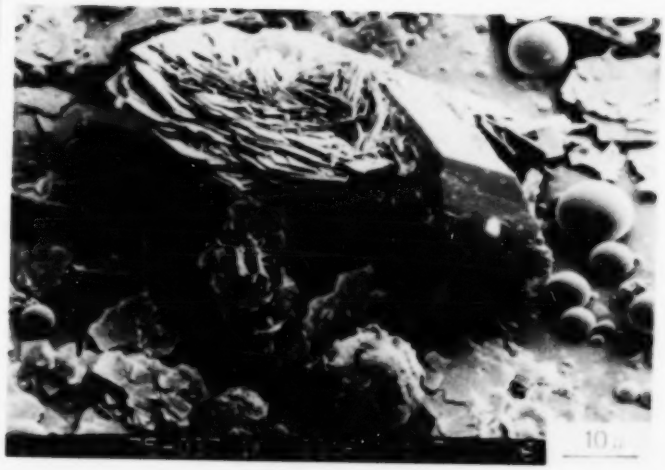

Figure 8A

Figure 8B

Figure 8C

Figure 8D

FIGURE 9

High-magnification photomicrographs of sulfite-gypsum "Mixed Crystal" forms.

A. Sulfite rosette in intimate physical association with a well-developed gypsum crystal

B. Sulfite rosette in intimate physical association with a well-developed gypsum crystal

C. Contact zone of sulfite and gypsum mixed crystal (note: arrow)

D. Contact zone of sulfite and gypsum mixed crystal (note: arrow)

Figure 9A

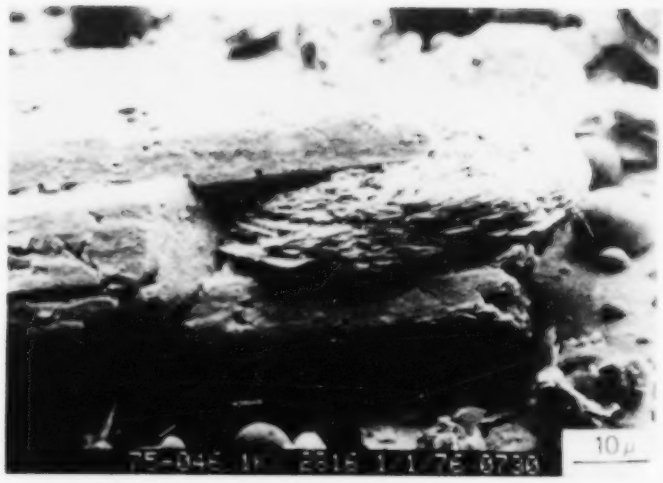

Figure 9B

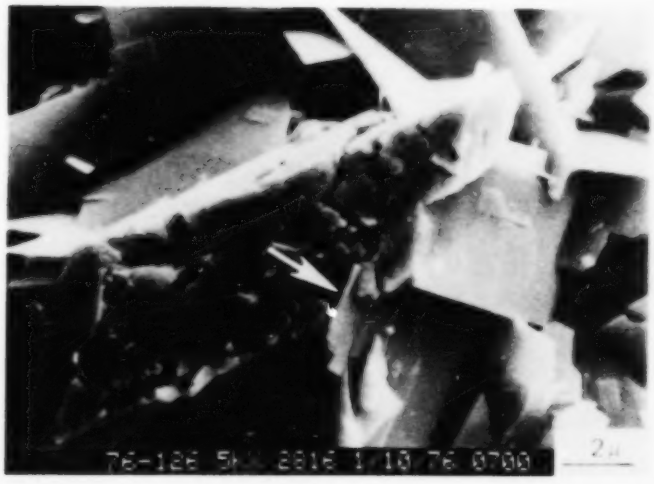

Figure 9C

Figure 9D

FIGURE 10

Photomicrographs of sludge solids components with and without forced oxidation on the same system (venturi/spray tower).

A. Flat sulfite plates formed with no forced oxidation in the spray tower

B. Gypsum crystals formed with forced oxidation in the venturi

C. Enlargement of the sulfite plates shown in A

D. Enlargement of the gypsum crystals shown in B

E. High-magnification of the sulfite plates shown in A

F. High-magnification of the gypsum crystals shown in B

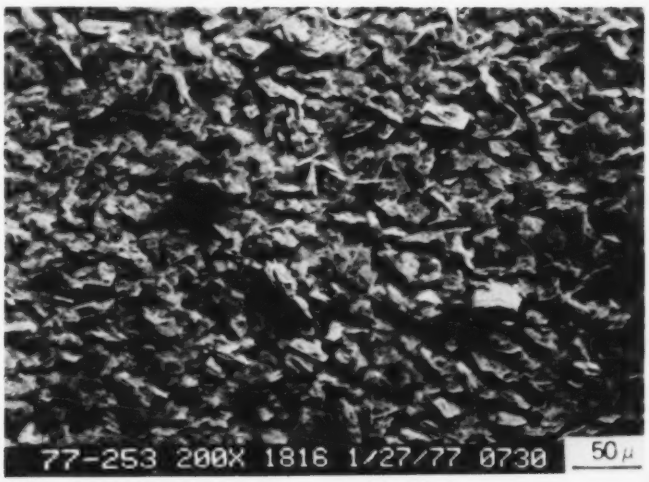

Figure 10A

Figure 10B

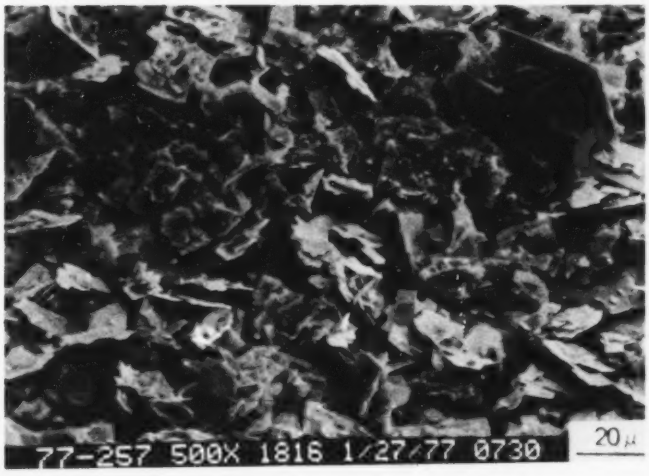

Figure 10C

Figure 10D

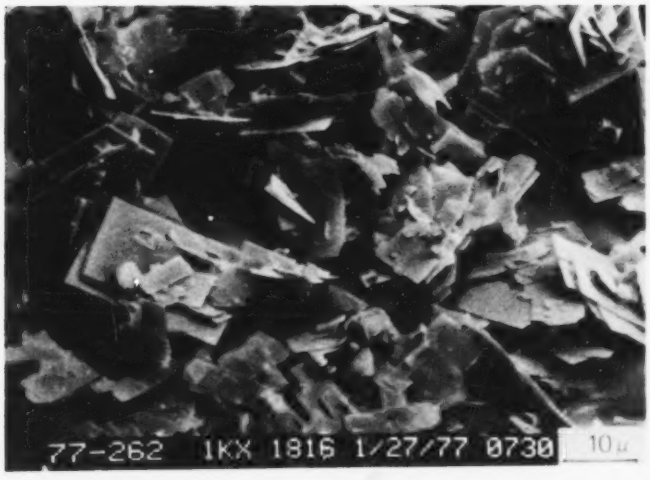

Figure 10E

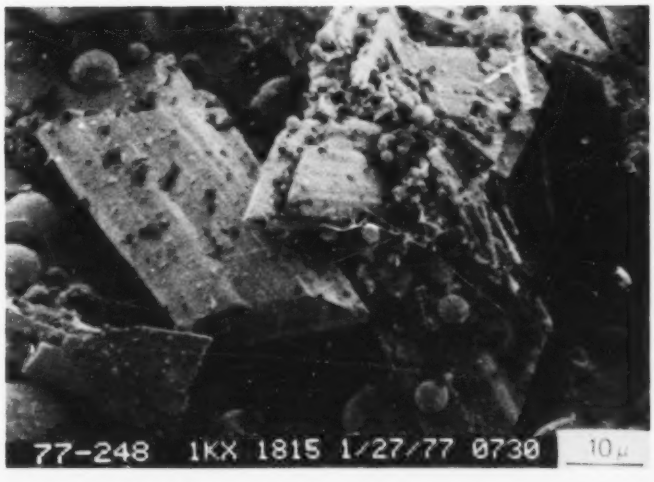

Figure 10F

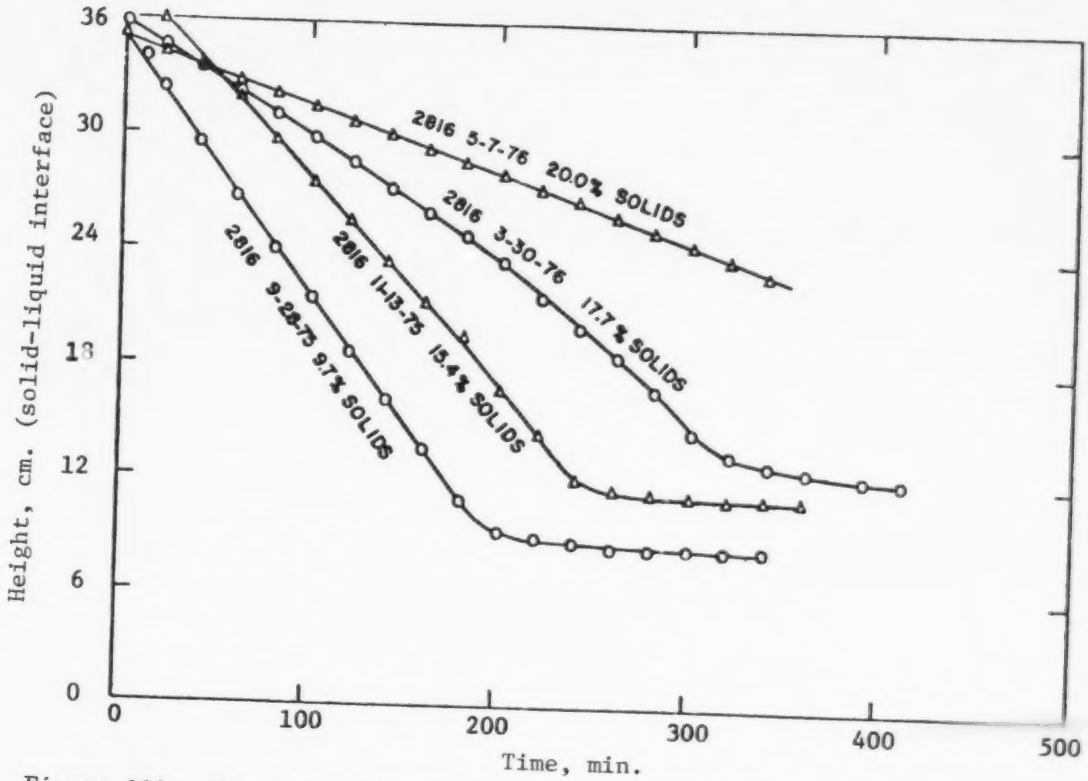

Figure 11A. Similar particulate morphology but different slurry percent solids

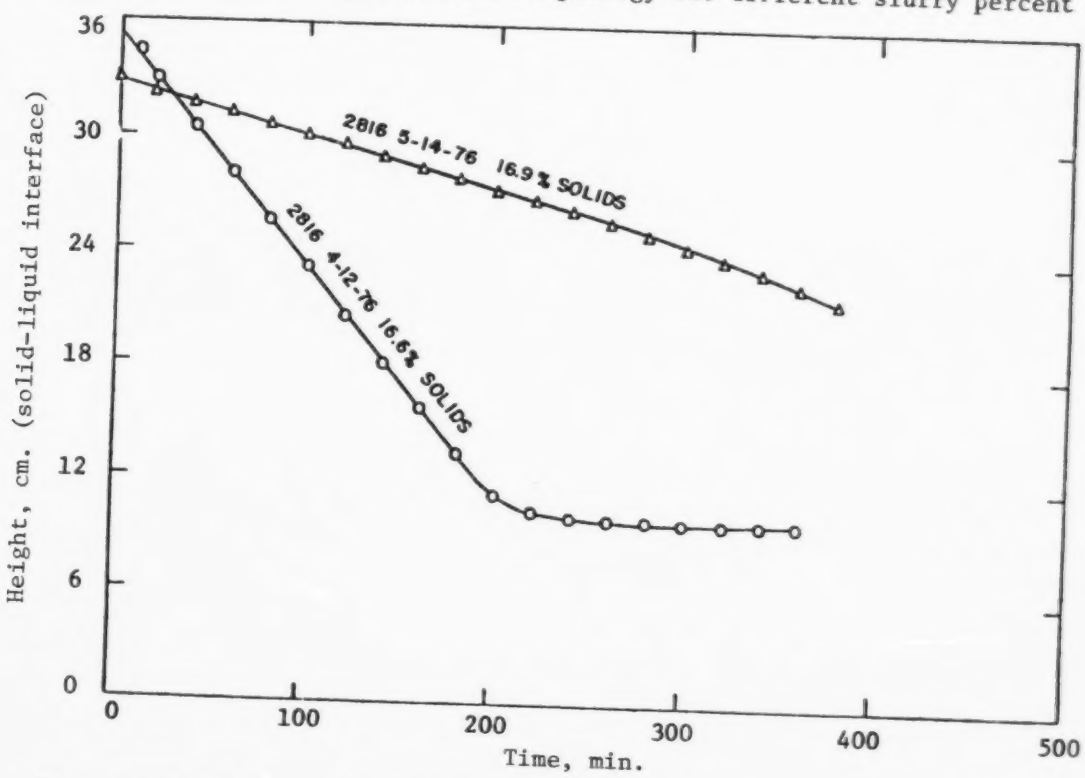

Figure 11B. Different particulate morphology but similar slurry percent solids

Figure 11. Slurry settling rate curves

FIGURE 12

Photomicrographs of solids producing settling behavior shown in Figure 11B.

A. Small sulfite plates and plate fragments in TCA scrubbing slurry sample of 5/14/76

B. Large sulfite plates in TCA scrubbing slurry sample of 4/12/76

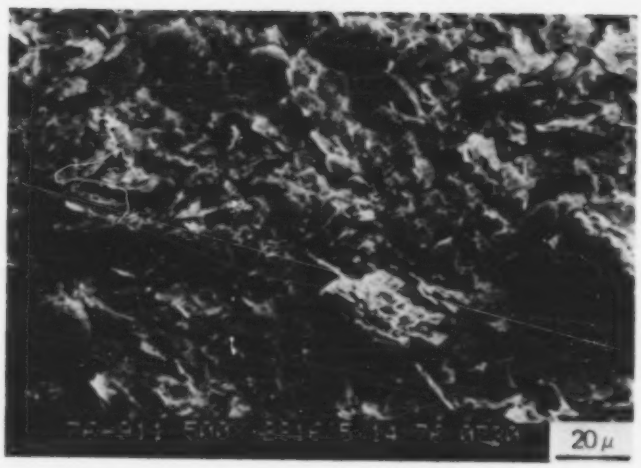

Figure 12A

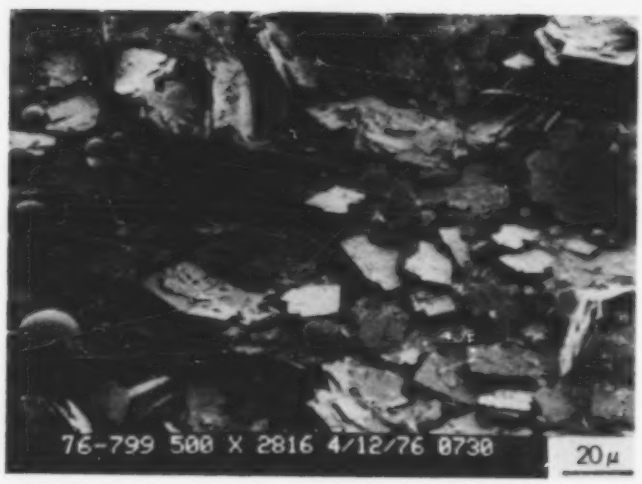

Figure 12B

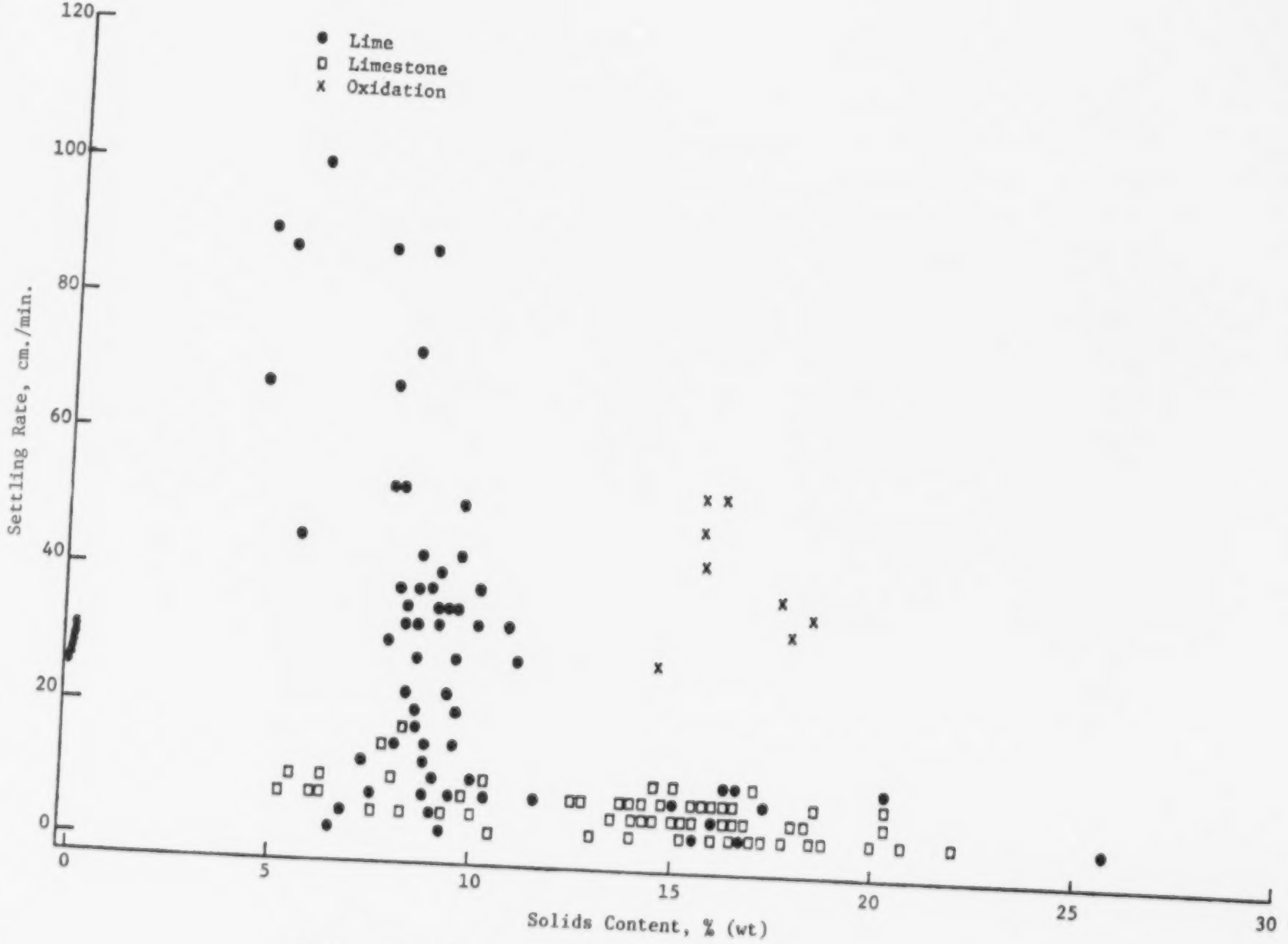

Figure 13. Settling rate of lime and limestone scrubber slurries

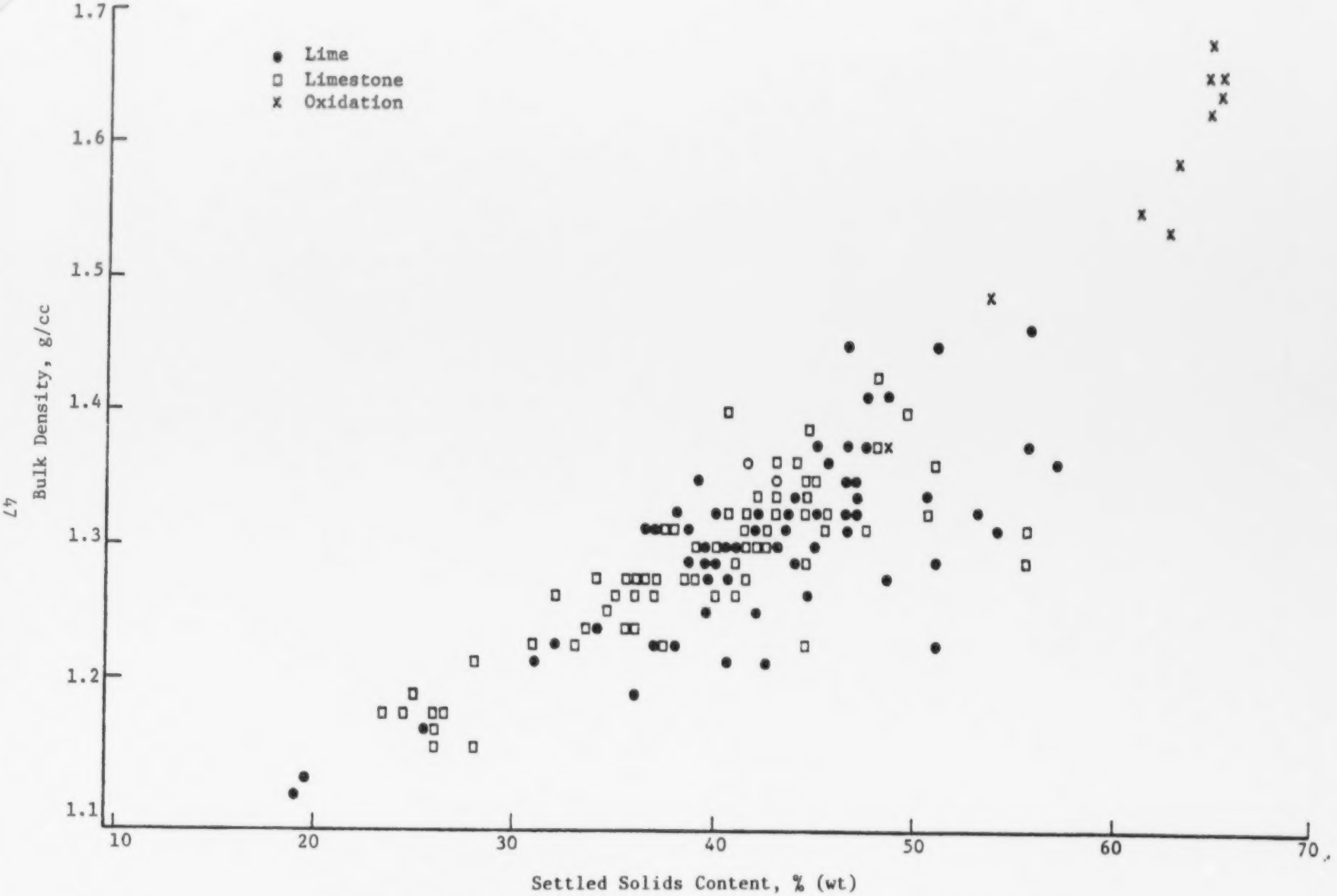

Figure 14. Settled bulk density for lime and limestone scrubber slurries

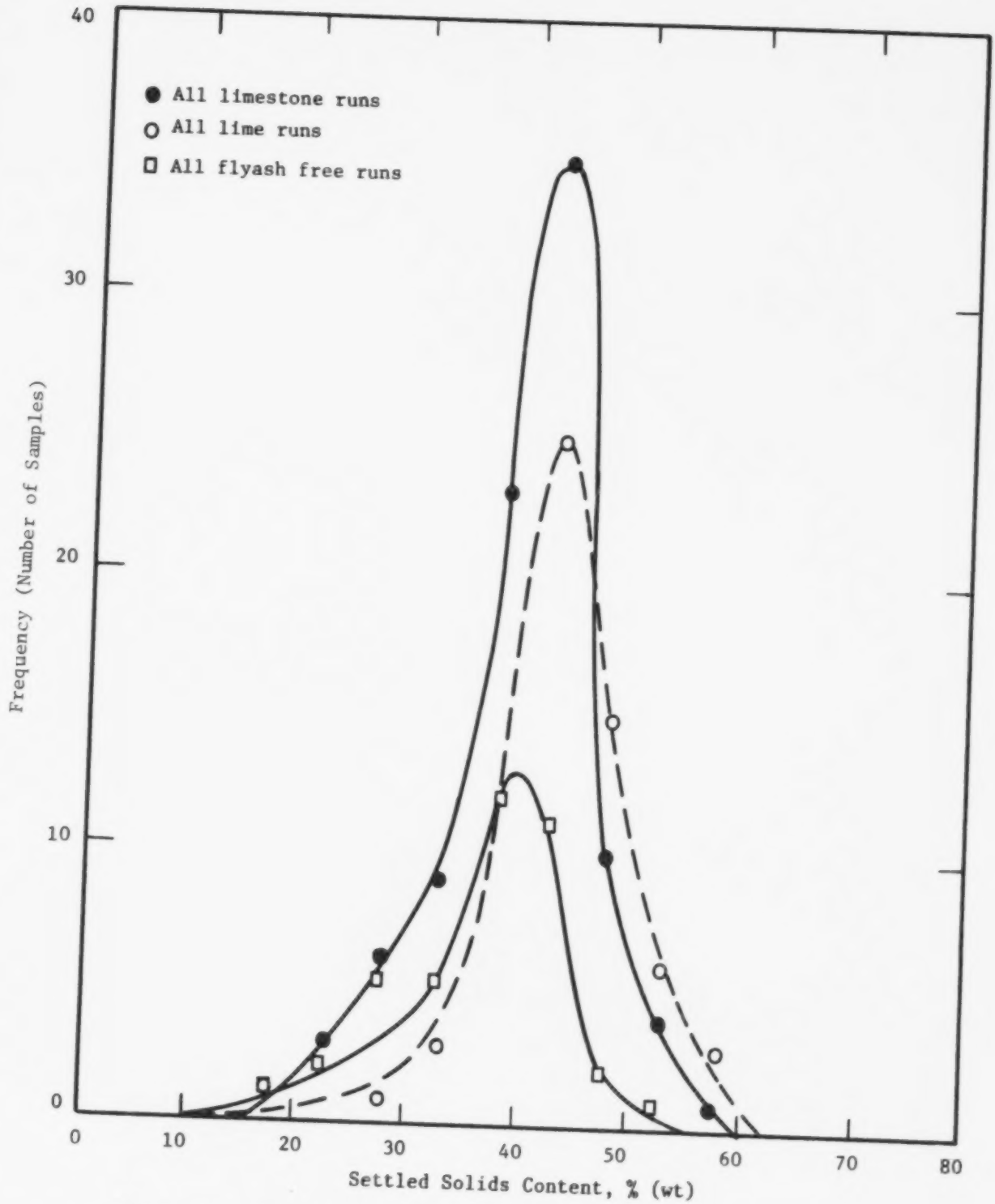

Figure 15. Distribution of settled solids content values for solids produced under lime, limestone, and fly ash-free operation

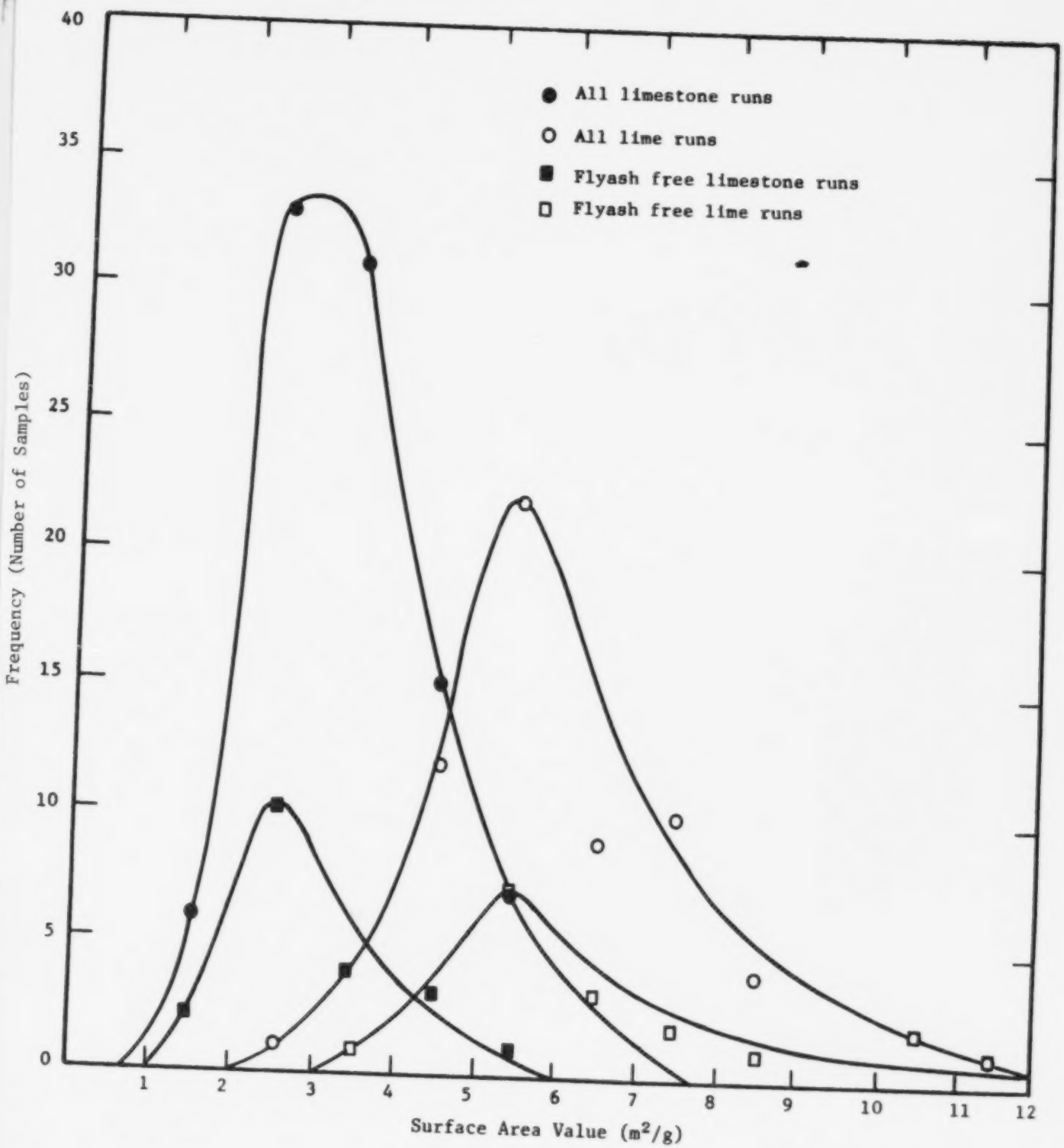

Figure 16. Distribution of surface area values for solids produced under lime, limestone, and fly ash-free operation

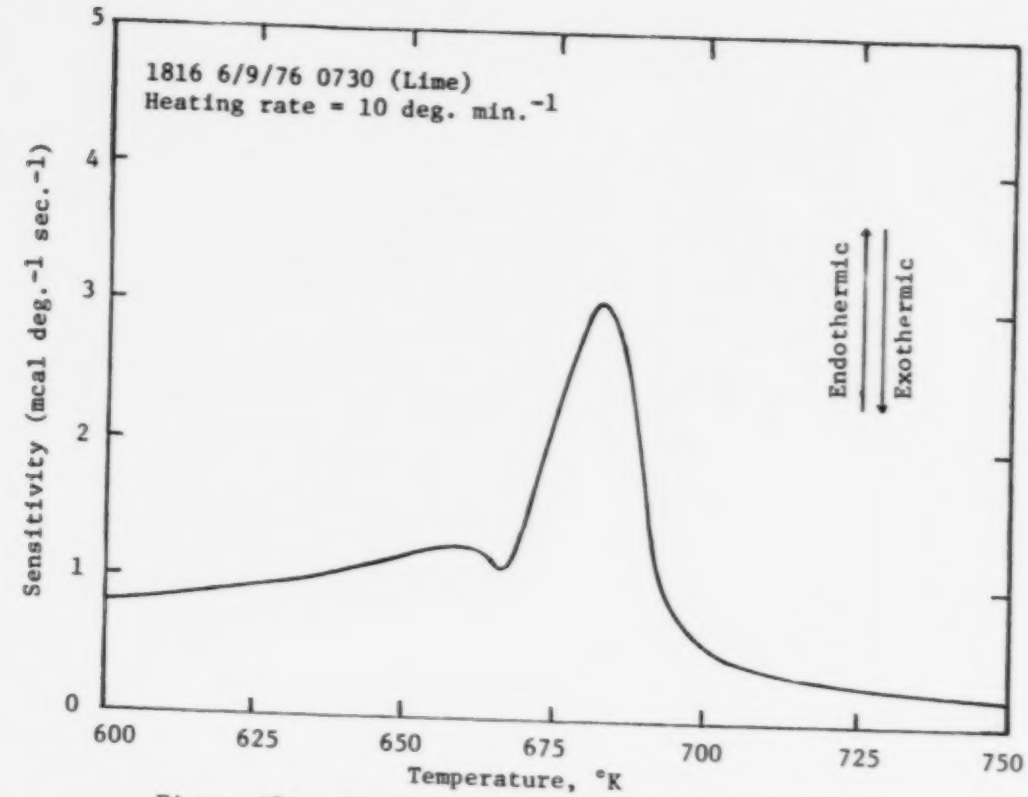

Figure 17A. Thermogram for limestone product sludge

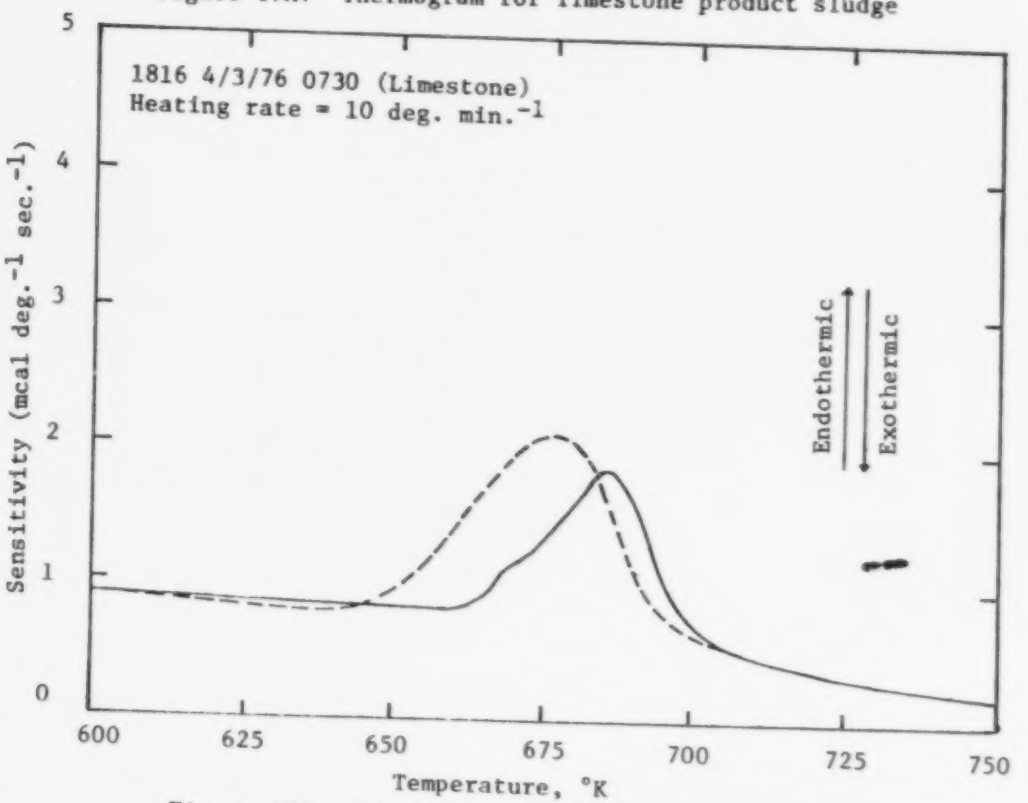

Figure 17B. Thermogram for limestone product sludge

Figure 17. Thermograms for lime- and limestone-produced sludge

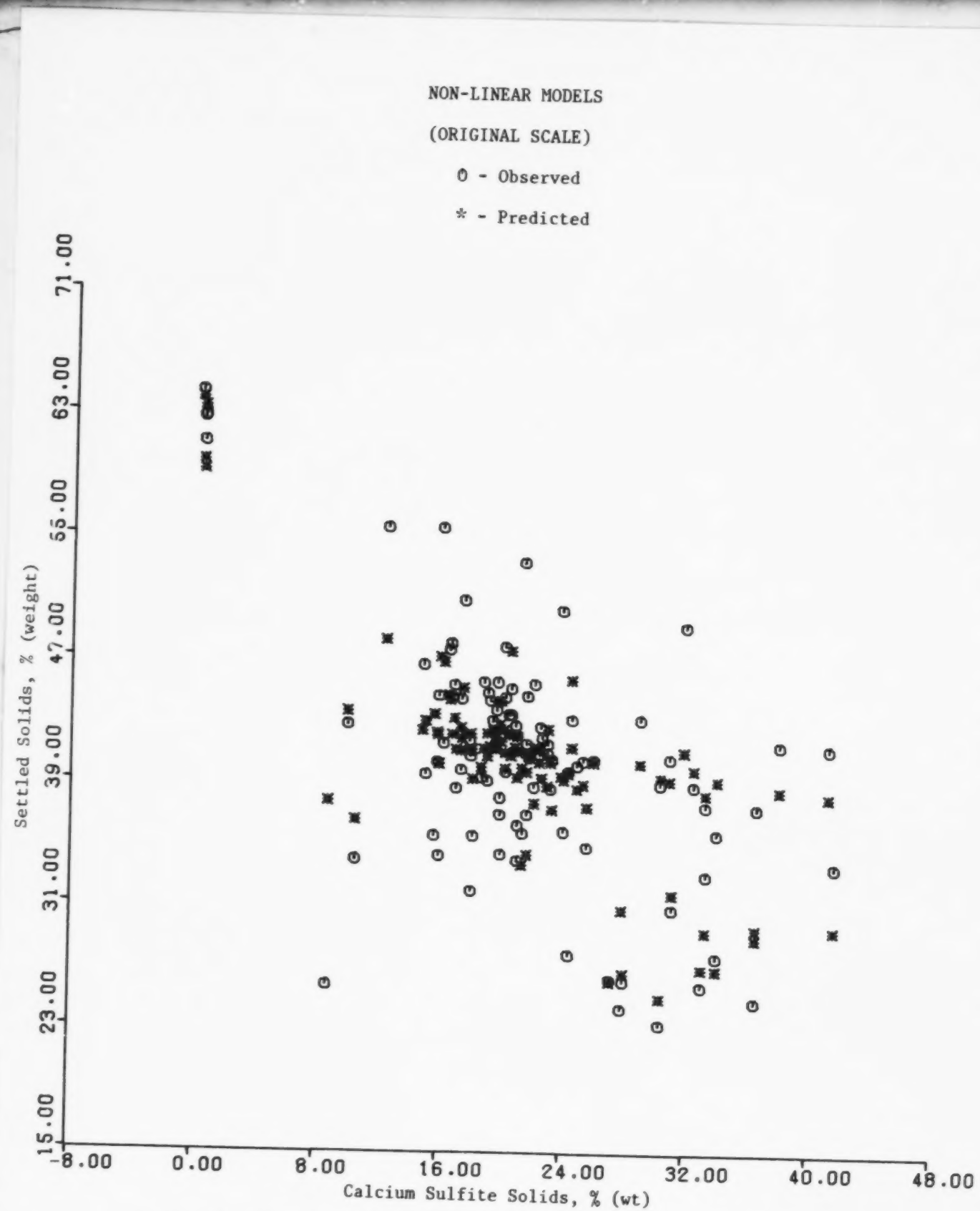

Figure 18. Final settled solids content of limestone scrubber slurries as a function of sulfite content

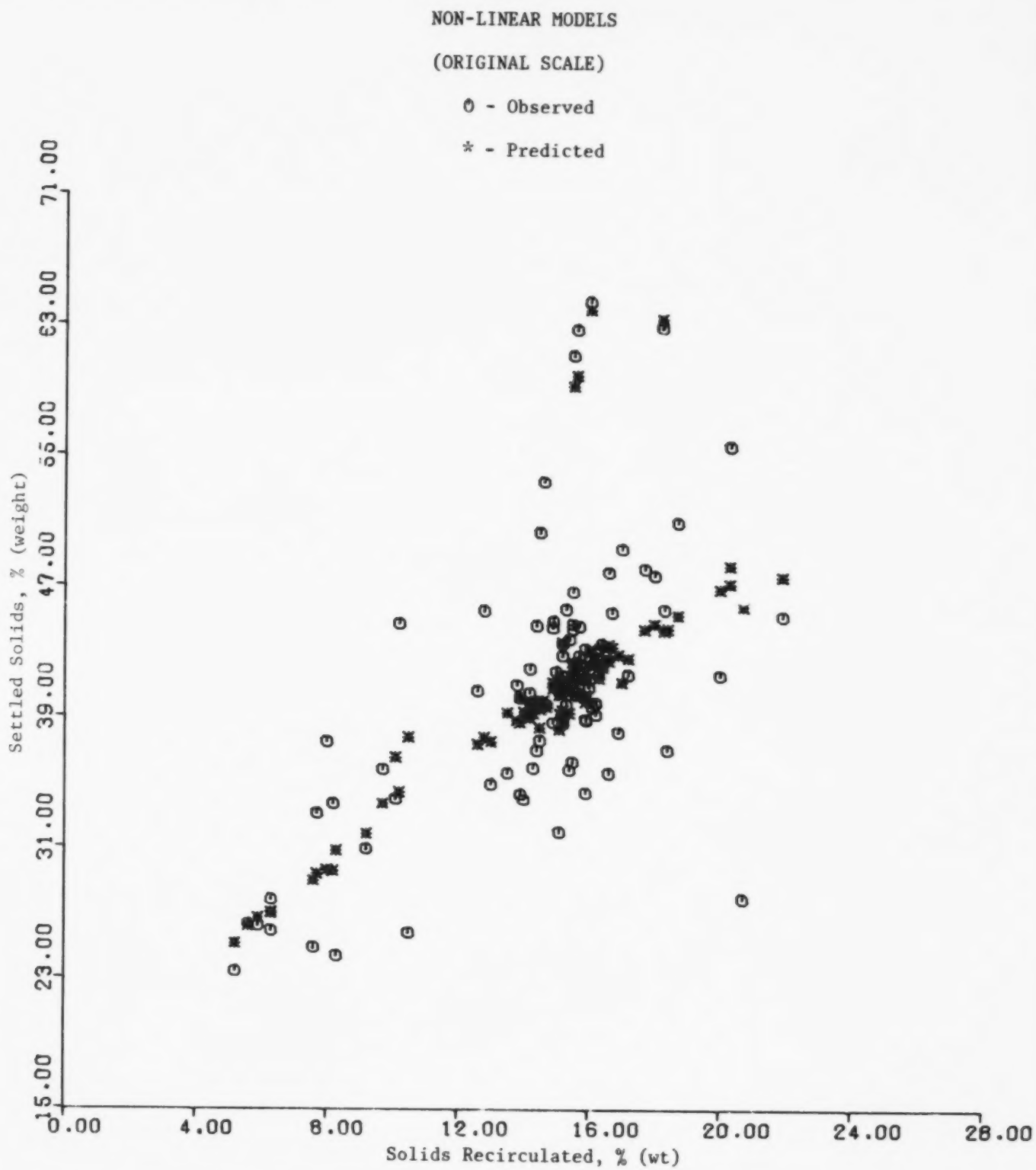

Figure 19. Final settled solids content of limestone scrubber slurries as a function of recirculated solids

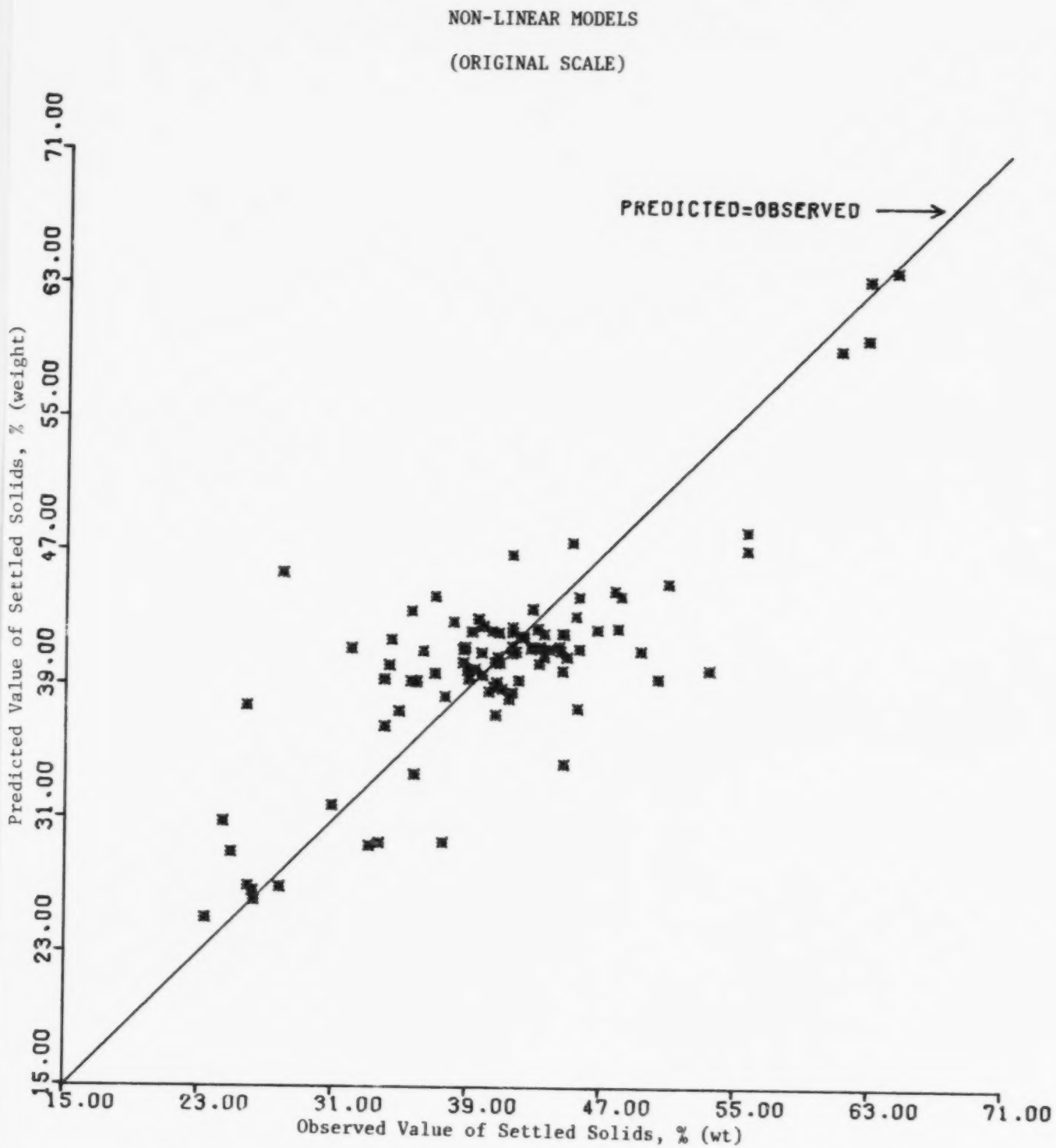

Figure 20. Predicted and observed final settled solids content for limestone scrubber slurries

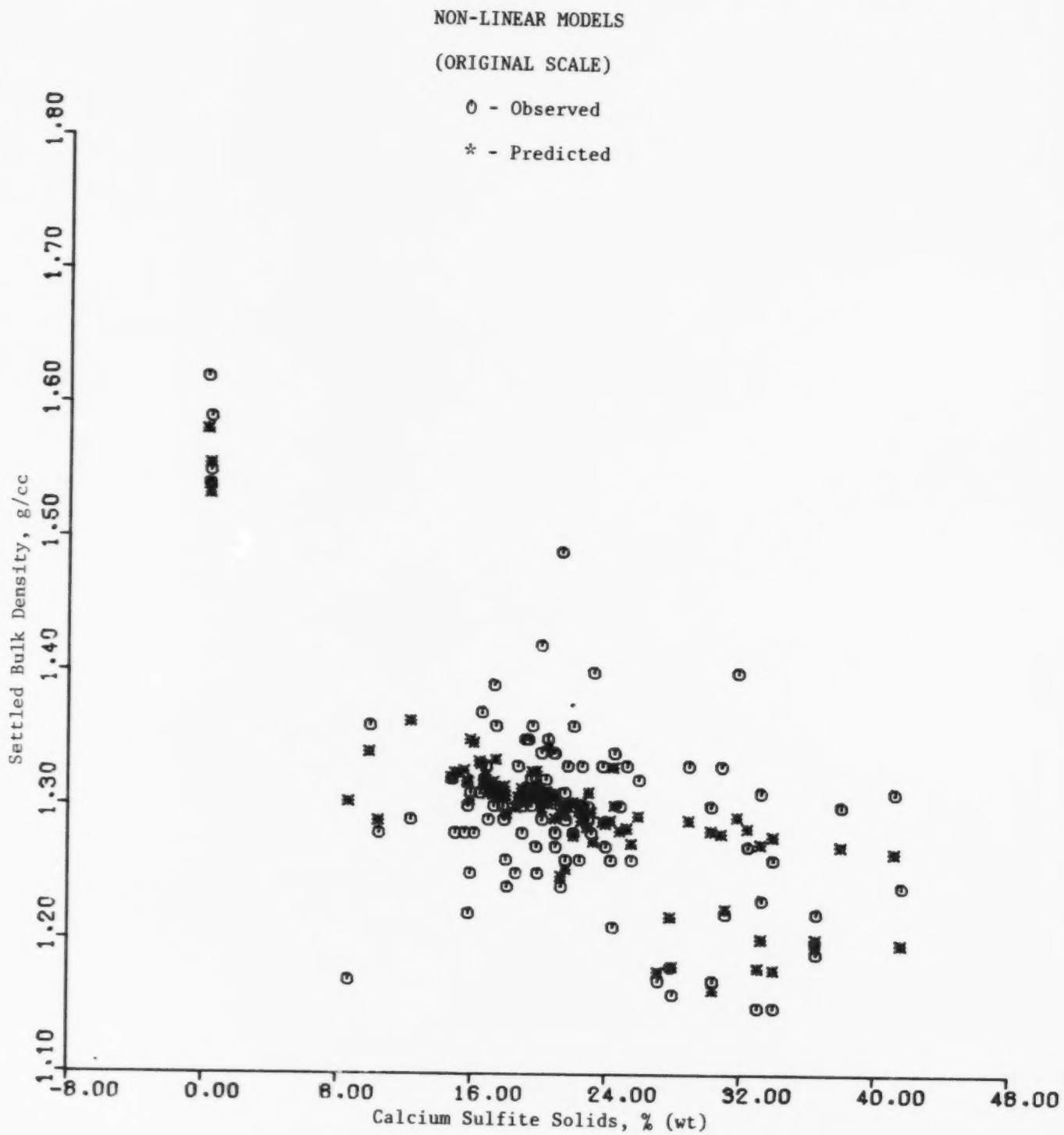

Figure 21. Settled bulk density of limestone scrubber slurries as a function of sulfite content

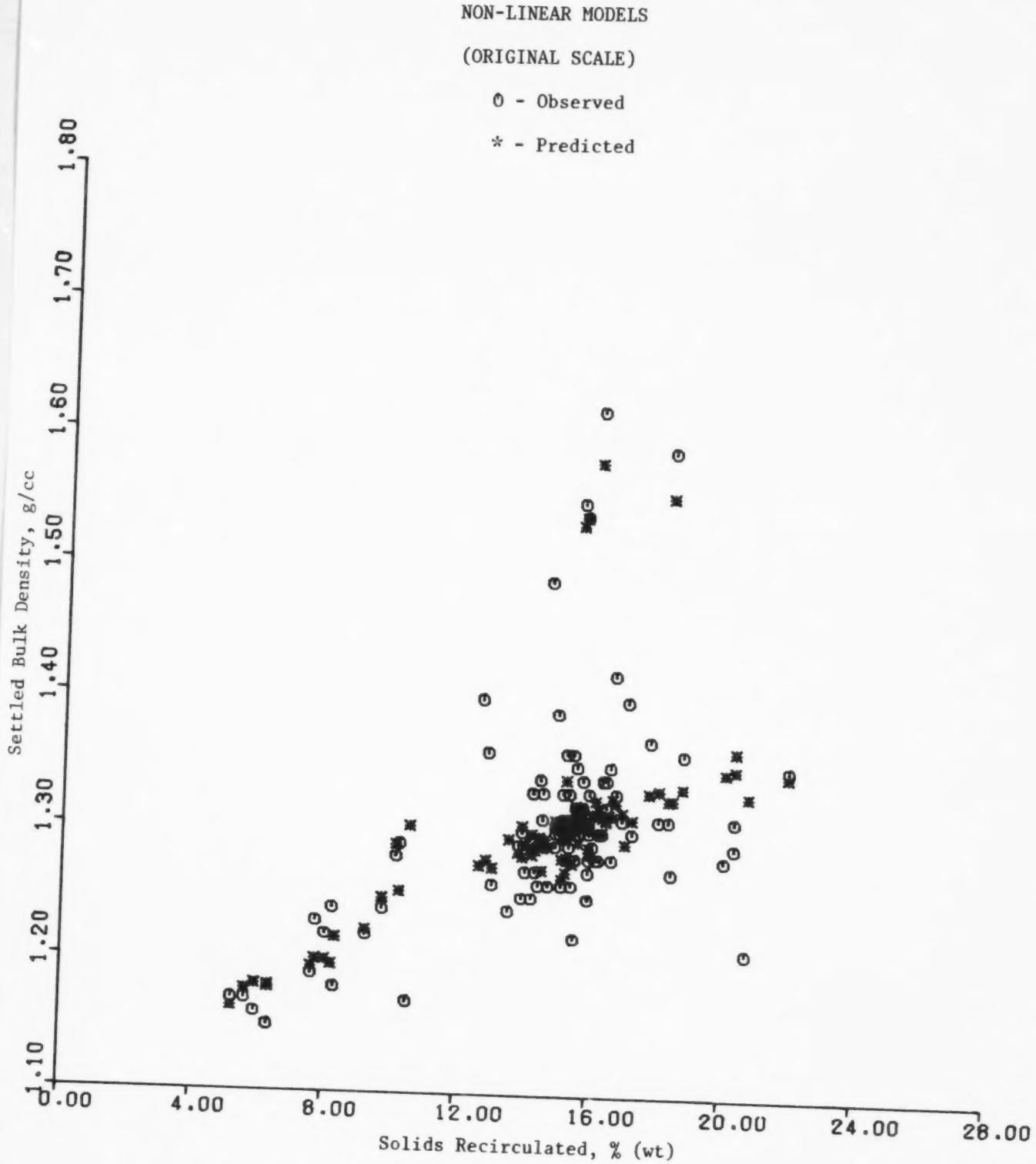

Figure 22. Settled bulk density of limestone scrubber slurries as a function of recirculated solids content

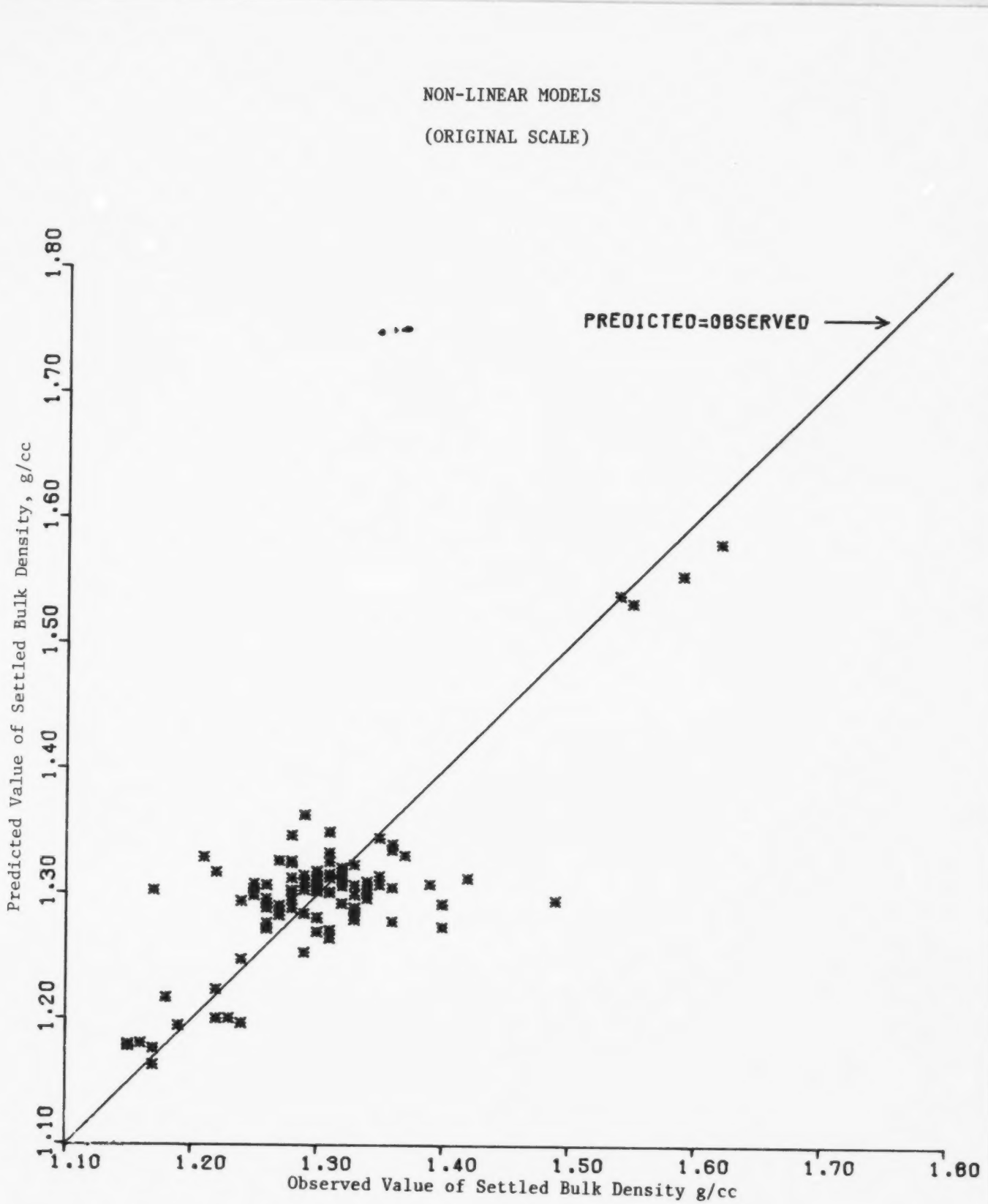

Figure 23. Predicted and observed settled bulk density for limestone scrubber slurries

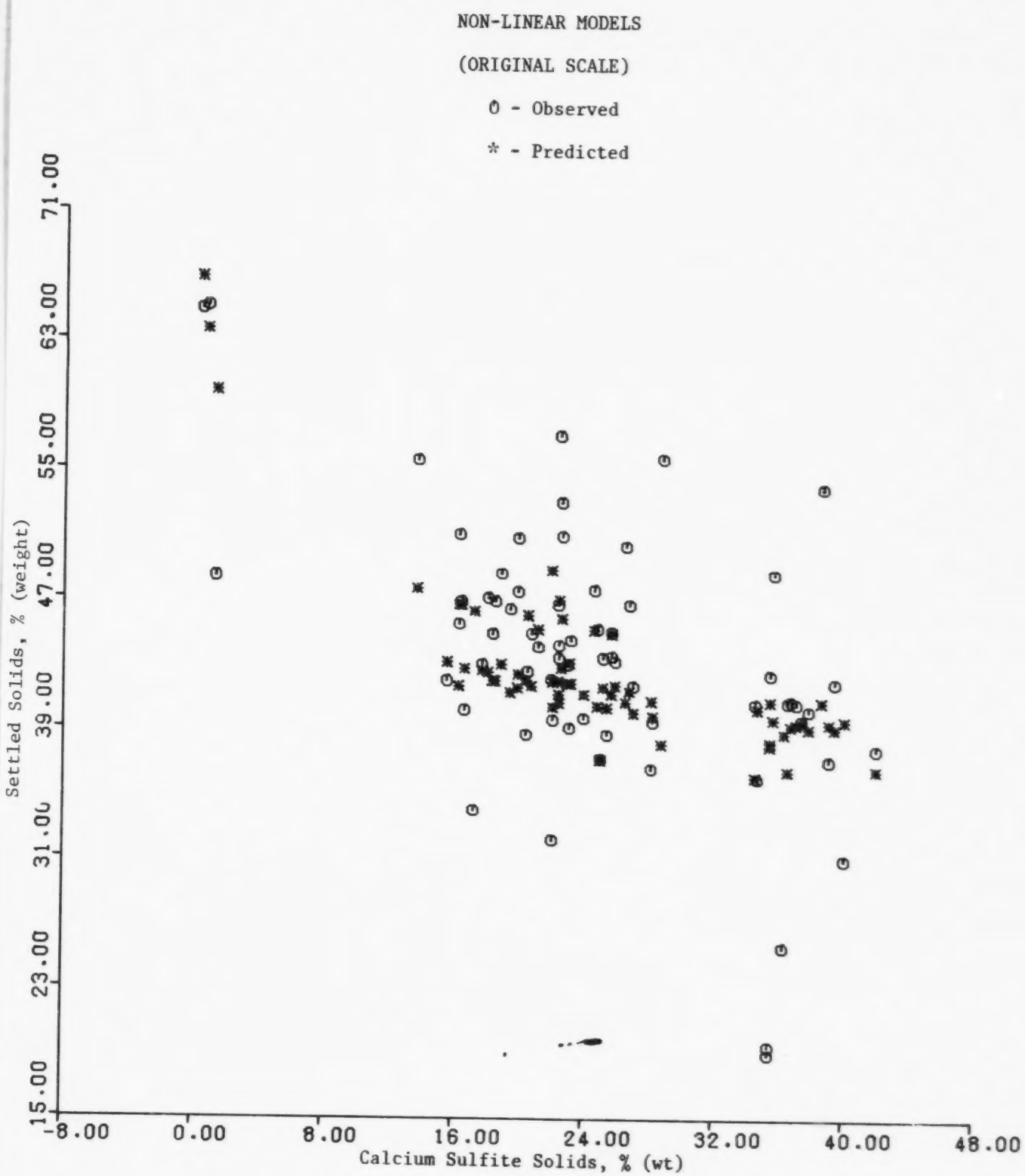

Figure 24. Final settled solids content of limestone scrubber slurries as a function of sulfite content

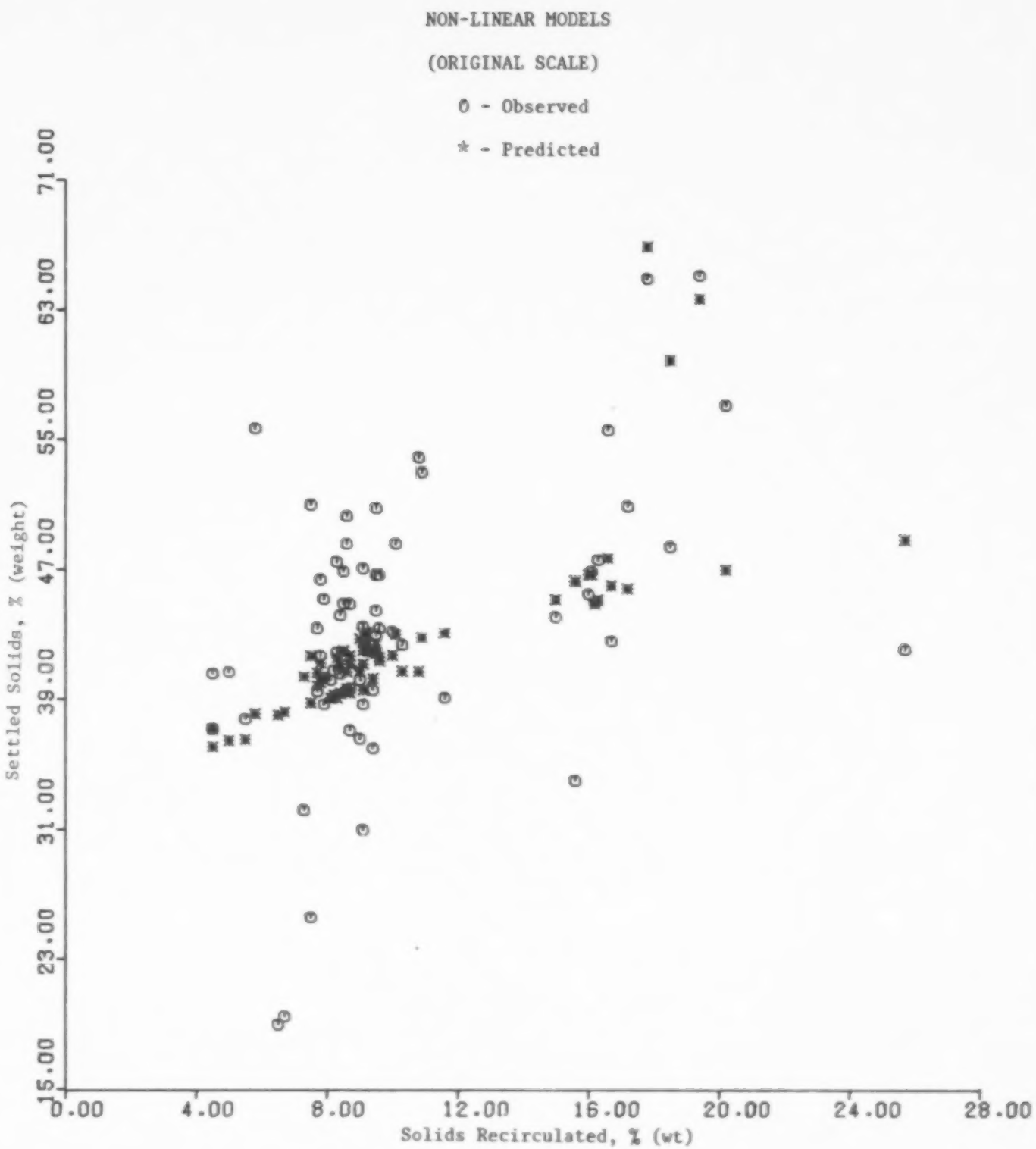

Figure 25. Final settled solids content of lime scrubber slurries as a function of recirculated solids content

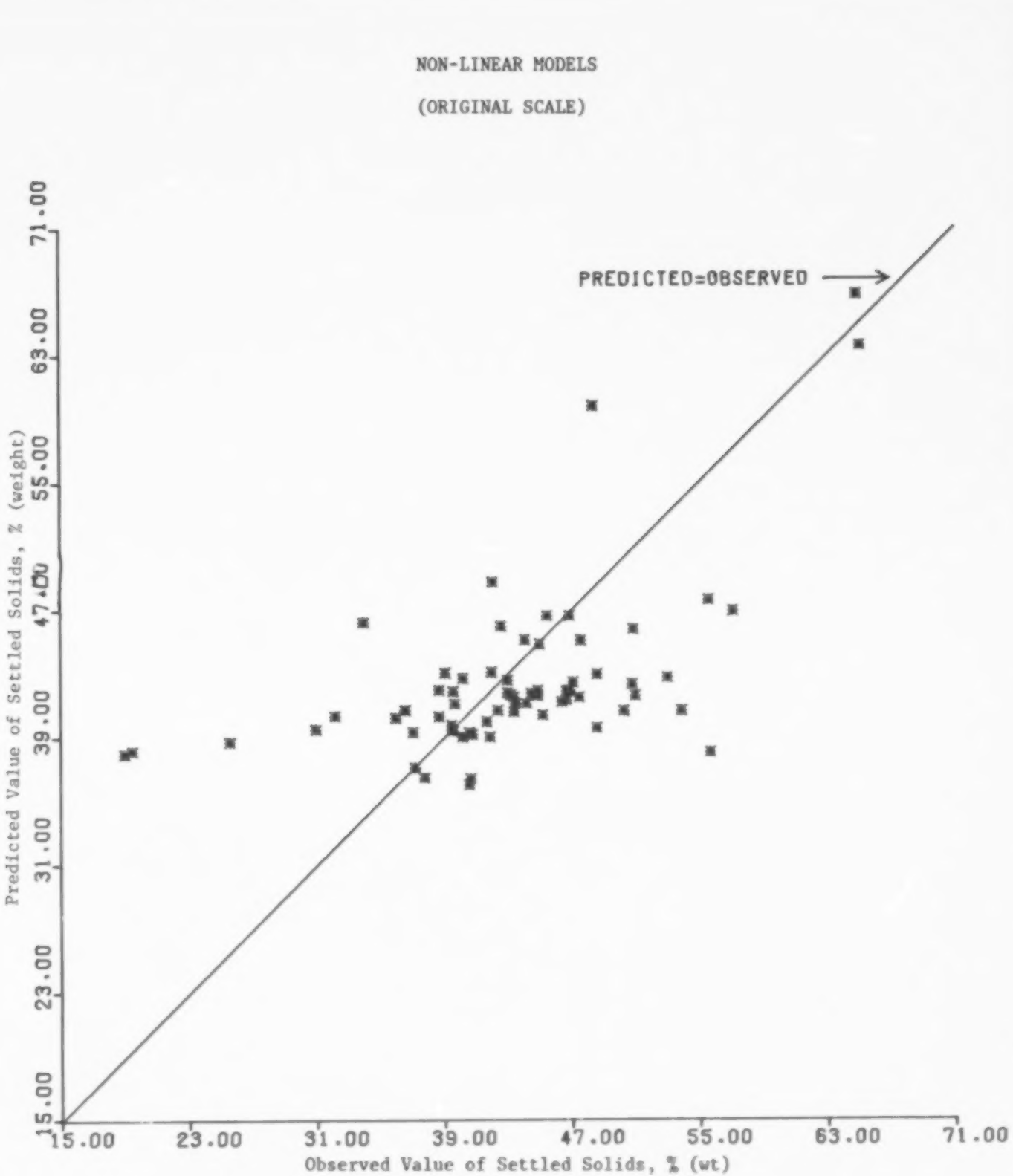

Figure 26. Predicted and observed final settled solids content for lime scrubber slurries

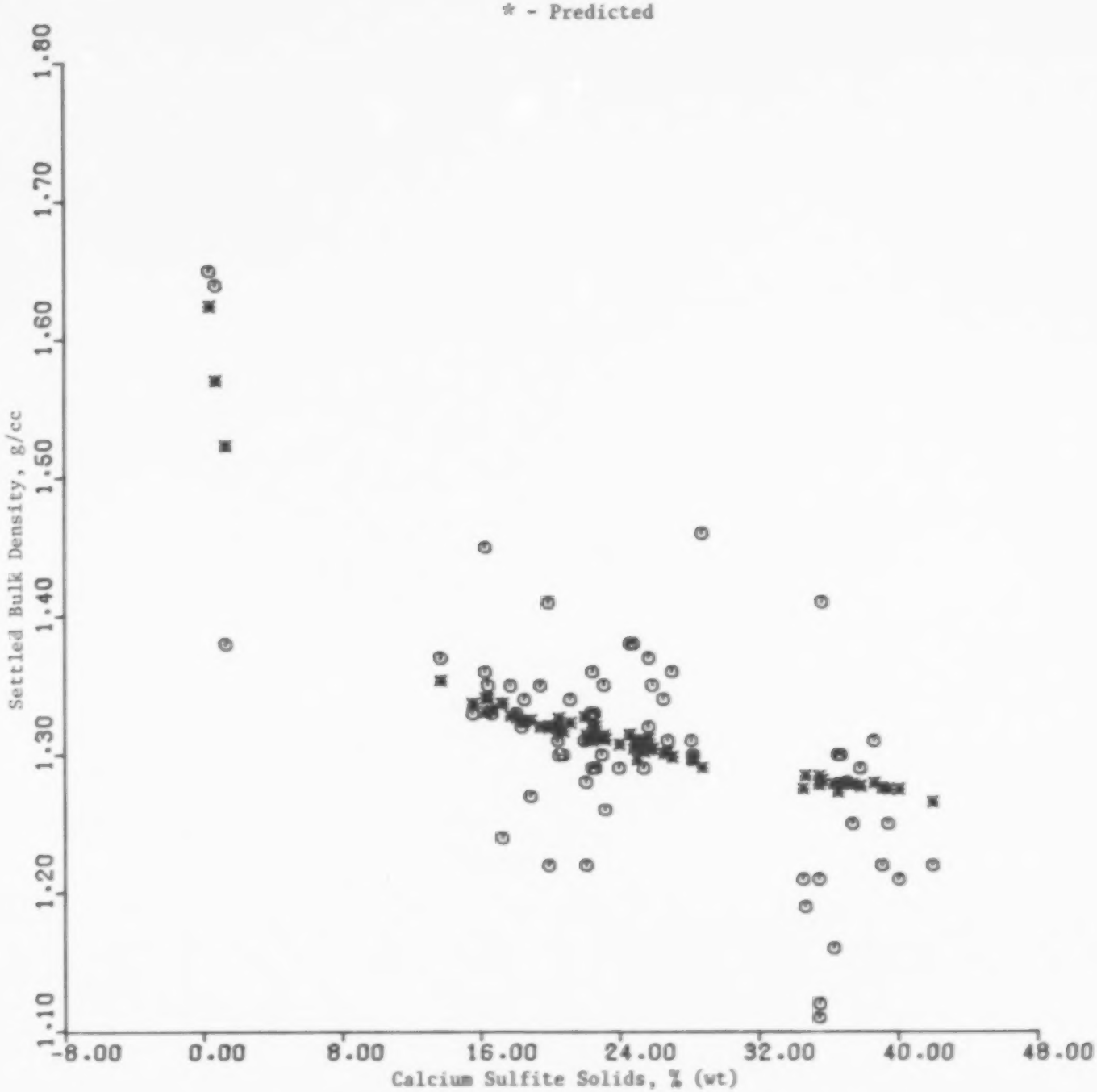

Figure 27. Settled bulk density of lime scrubber slurries as a function of sulfite content

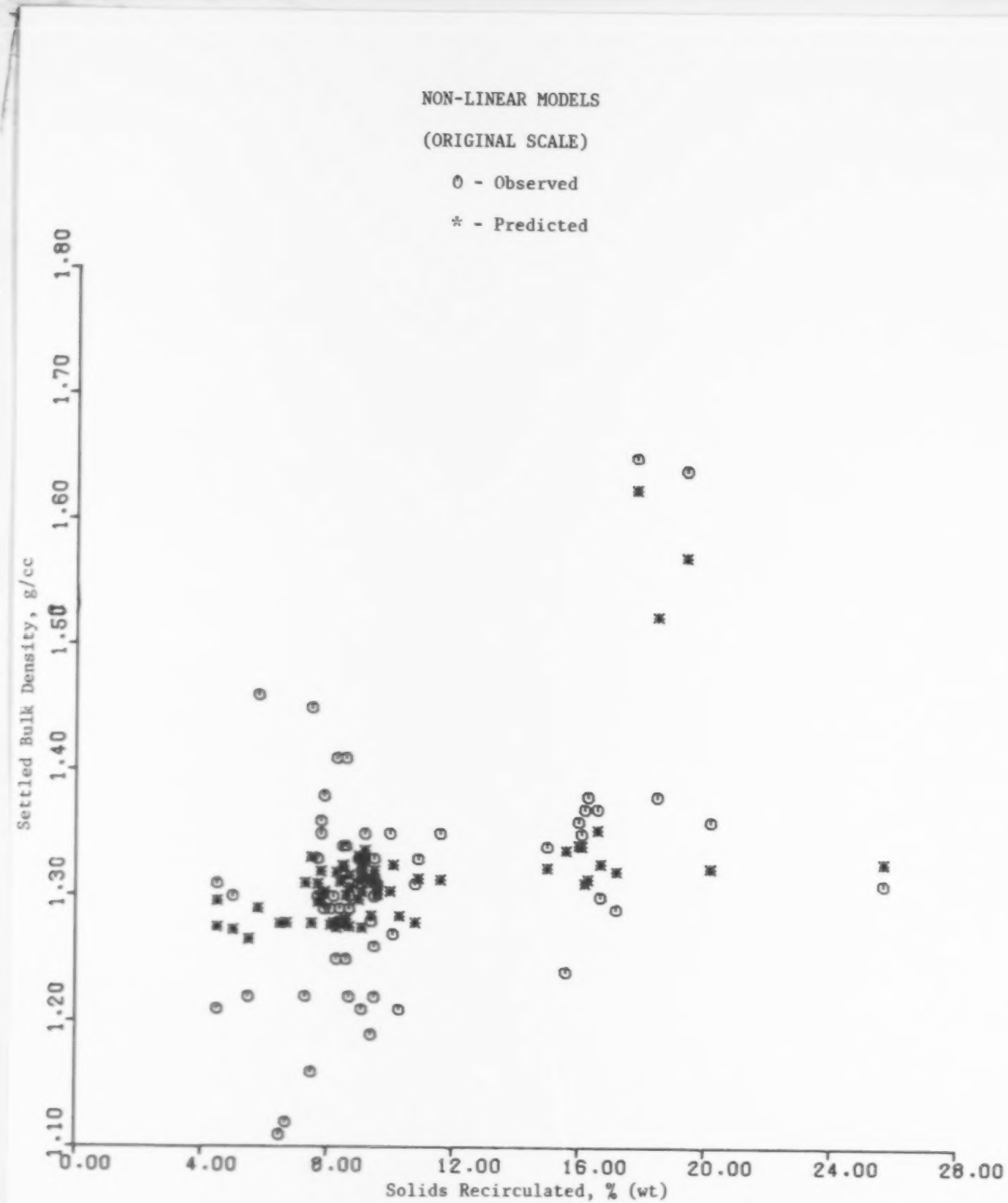

Figure 28. Settled bulk density of lime scrubber slurries as a function recirculated solids content

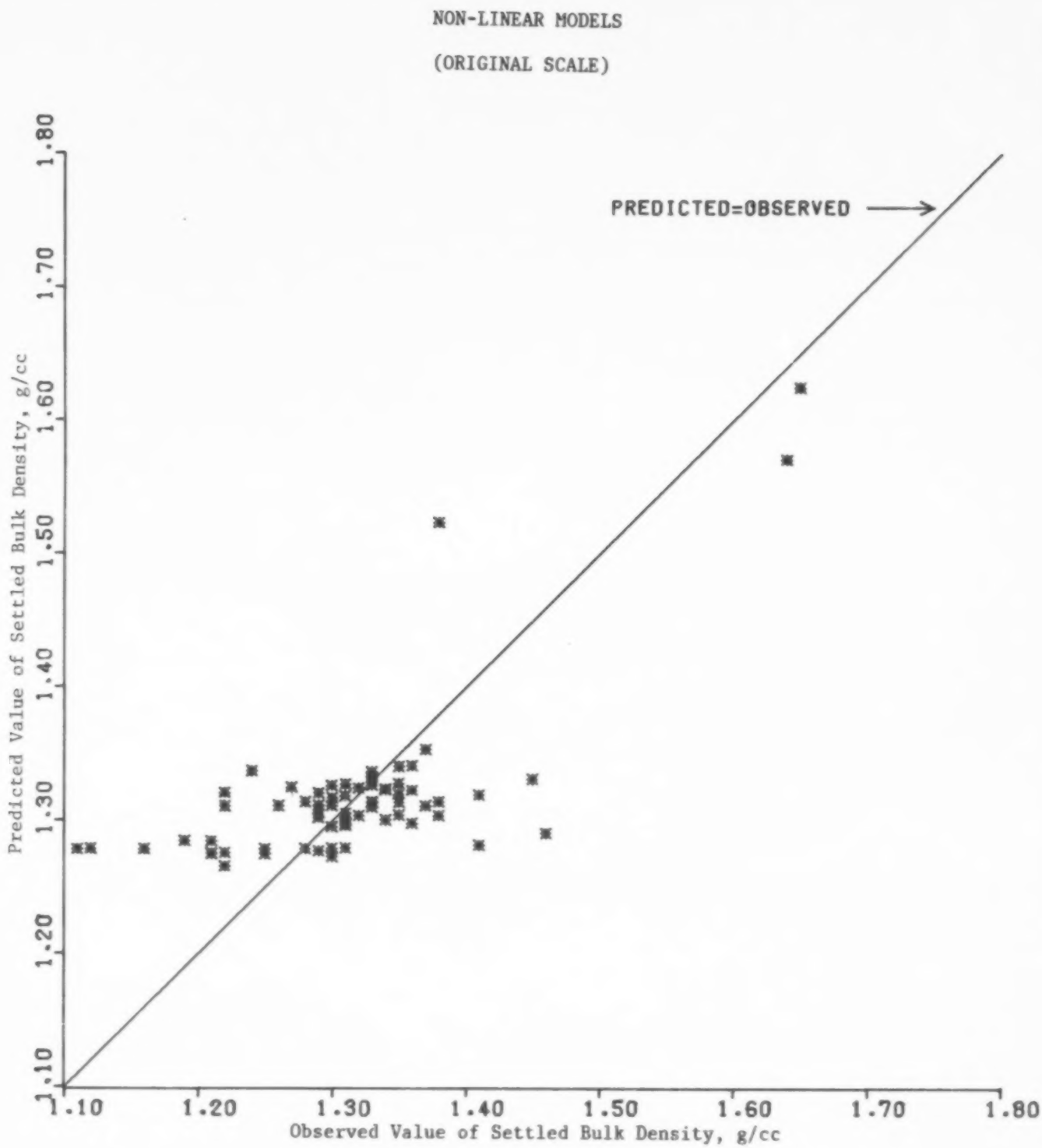

Figure 29. Predicted and observed settled bulk density of lime scrubber slurries

TABLE 1. TCA SLURRY ANALYSES

RUN NUMBER	539-2A	539-2A	541-2A	546-2A	546-2A	546-2A	557-2A	559-2A	559-2A	560-2A	561-2A	562-2A	562-2A
ANALYSIS POINT	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816
DATE	031375	031475	032675	061175	061275	061775	080875	091475	092175	092875	100575	101275	102175
TIME	1300	1300	1500	1500	0700	0700	1426	0700	0700	0700	0700	0700	0700
ADSORBENT	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS
ON-SITE SOLIDS ANALYSES													
ASH (WT %)	28.81	27.43	23.47	47.53	38.72	29.55	39.55	35.62	38.08	32.34	31.98	28.39	33.68
CA (WT %)	31.33	31.38	34.96	23.92	25.84	30.18	27.05	28.93	27.89	30.29	28.73	30.42	31.20
SO2 (WT %)	15.81	18.11	15.91	19.03	22.05	25.95	14.80	17.30	15.01	21.32	22.42	20.18	18.62
SO3 (WT %)	7.08	6.05	8.11	3.46	4.42	3.66	5.61	4.95	5.84	3.70	5.02	7.43	6.12
CO2 (WT %)	11.36	11.25	12.06	2.55	3.78	5.21	8.50	8.66	8.65	7.78	6.13	7.26	6.15
TVA SOLIDS CHARACTERIZATION													
ASH (WT %, ACID INSOLUBLE)	25.0	33.0	29.0	43.3	43.3	26.7	42.0	35.0	30.0	35.7	29.0	28.0	29.0
CACO3 (WT %, BY IR)	32.0	28.0	33.0	11.6	13.3	16.9	14.6	20.1	18.1	35.7	16.1	18.6	21.3
CASO3 X .5 H2O (WT %, IR)	36.0	39.0	29.0	34.7	32.1	48.0	32.5	35.9	42.2	30.7	46.2	45.6	41.2
CASO4 X 2H2O (WT %, IR)	6.8	0.0	8.7	10.4	11.3	8.4	10.9	9.0	9.7	8.4	8.7	7.7	8.5
SURFACE AREA (SQ M/GM)	3.8	4.4	3.5	2.8	2.6	2.5	2.4	3.7	2.8	3.4	2.5	2.7	3.5
TVA SLURRY CHARACTERIZATION													
SLURRY SOLIDS %	15.5	13.5	13.9	14.9	15.9	15.6	15.5	16.2	16.1	9.7	15.1	15.3	14.2
SETTLED % SOLIDS	44.7	35.6	34.3	44.9	38.8	40.6	46.7	39.9	39.6	35.8	40.9	39.8	39.4
SETTLED BULK DENSITY(GM/CC)	1.22	1.24	1.25	1.30	1.28	1.32	1.32	1.30	1.28	1.24	1.26	1.29	1.25
SETTLING RATE (CM/HR)	5.0	4.7	3.4	6.6	4.8	5.3	7.3	4.3	4.7	7.9	5.8	5.0	4.6
TVA CRYSTALLOGRAPHIC ANALYSES													
SULFITE REFRACTIVE INDEX	1.590	1.590	1.591	1.590	1.590	1.593	1.591	1.589	1.591	1.590	1.589	1.590	1.589
SULFITE A AXIS	9.790	9.798	9.780	9.795	9.790	9.800	9.791	9.786	9.787	9.792	9.797	9.794	9.788
STD. ERROR	0.017	0.016	0.028	0.006	0.010	0.015	0.009	0.008	0.003	0.017	0.006	0.006	0.007
SULFITE B AXIS	10.678	10.661	10.640	10.695	10.694	10.680	10.730	10.700	10.697	10.693	10.697	10.697	10.702
STD. ERROR	0.010	0.009	0.014	0.007	0.012	0.014	0.010	0.008	0.005	0.012	0.006	0.006	0.007
SULFITE C AXIS	6.503	6.492	6.491	6.551	6.518	6.515	6.517	6.520	6.517	6.510	6.514	6.514	6.512
STD. ERROR	0.008	0.008	0.012	0.004	0.010	0.012	0.008	0.006	0.004	0.010	0.005	0.005	0.005
SCRUBBER OPERATIONAL PARAMETERS													
% SOLID OXIDATION	26.40	0.0	28.90	12.70	13.80	10.10	23.27	18.60	23.70	12.10	15.10	22.80	20.80
SAT. RATIO (RADIAN 50 C.)	0.0	0.0	1.08	1.21	1.10	0.40	0.97	0.46	0.43	0.37	0.35	0.49	0.0
STOIC. RATIO	1.67	1.56	1.76	1.25	1.15	1.14	1.60	1.55	1.62	1.42	1.24	1.33	1.52
SLURRY PH	6.00	6.00	5.85	5.70	5.65	5.95	5.95	6.05	5.40	5.70	5.95	5.85	5.80
SLURRY TEMPERATURE (C)	50.0	52.0	52.0	50.0	52.0	50.0	54.0	52.0	53.0	50.0	50.0	54.0	50.0
MAKE/PASS (MOLES/THOUS GAL)	0.0	0.0	0.0	60.0	86.5	107.4	83.5	85.9	92.8	0.0	89.8	79.2	84.6
LIQ/GAS (GAL/THOUS CFM)	0.0	0.0	0.0	33.4	34.1	33.9	40.9	40.3	40.0	42.0	40.0	40.5	40.3
WT % CL IN LIQUOR	0.19	0.16	0.15	0.33	0.26	0.20	0.18	0.18	0.19	0.17	0.0	0.22	0.0
WT % MG IN LIQUOR	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.04	0.04	0.0	0.03	0.0
HOLD TANK RES. TIME (MINS)	25.0	25.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	12.0	12.0

LS = Limestone

TABLE 1. TCA SLURRY ANALYSES

RUN NUMBER	562-2A	562-2A	563-2A	564-2A	565-2A	567-2A	568-2A	570-2A	571-2A	568-2B	575-2A	577-2A	579-2A
ANALYSIS POINT	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816
DATE	102875	110675	111375	111875	112875	120775	121475	122575	010176	011076	011676	012376	020176
TIME	0900	0700	0700	0700	0700	0700	0700	0700	0700	0700	0730	0700	0730
ADSORBENT	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS
ON-SITE SOLIDS ANALYSES													
ASH (WT %)	29.58	30.68	26.88	43.03	30.82	30.51	46.02	42.82	44.01	46.16	41.33	41.74	45.12
CA (WT %)	32.78	29.27	30.71	24.18	28.89	30.57	21.48	24.70	24.65	23.16	24.89	25.98	22.05
SO2 (WT %)	20.53	23.13	19.59	22.93	20.98	20.82	21.54	22.56	16.98	19.01	24.28	21.58	16.72
SO3 (WT %)	3.06	4.48	5.01	3.78	7.35	4.36	4.38	2.81	5.43	5.59	3.52	2.20	8.64
CO2 (WT %)	10.10	6.73	11.75	1.35	5.55	8.69	1.24	2.79	4.46	1.39	1.17	4.66	1.37
TVA SOLIDS CHARACTERIZATION													
ASH (WT %, ACID INSOLUBLE)	27.0	33.0	25.0	40.0	24.0	30.0	27.0	32.0	42.0	47.0	32.5	29.2	44.5
CACO3 (WT %, BY IR)	29.2	18.5	30.1	2.0	9.8	19.7	4.8	17.6	8.1	2.3	4.4	14.2	1.4
CASO3 X .5 H2O (WT %, IR)	38.7	39.3	35.4	48.1	54.2	43.9	55.5	44.1	42.4	43.8	51.8	47.4	47.3
CASO4 X 2H2O (WT %, IR)	5.1	8.2	10.0	13.8	11.0	6.4	12.7	6.8	7.5	6.9	11.3	9.2	6.8
SURFACE AREA (SQ M/GM)	2.4	3.0	3.0	3.3	3.7	2.8	1.6	2.5	3.5	2.7	3.6	3.1	3.3
TVA SLURRY CHARACTERIZATION													
SLURRY SOLIDS %	21.9	15.2	15.4	13.8	14.0	15.7	15.5	14.2	14.9	16.2	14.7	14.4	15.7
SETTLED % SOLIDS	45.2	38.7	43.8	41.0	34.0	42.8	41.6	42.0	38.7	39.2	39.8	37.0	44.6
SETTLED BULK DENSITY(GM/CC)	1.35	1.28	1.36	1.29	1.27	1.34	1.31	1.33	1.29	1.28	1.26	1.26	1.32
SETTLING RATE (CM/HR)	3.6	5.7	6.7	7.5	4.8	6.3	8.0	4.3	6.3	5.4	6.9	6.0	7.7
TVA CRYSTALLOGRAPHIC ANALYSES													
SULFITE REFRACTIVE INDEX	1.590	1.589	1.593	1.592	1.590	1.590	1.591	1.593	1.590	0.0	1.592	1.591	1.591
SULFITE A AXIS	9.802	9.774	9.799	9.790	9.779	9.789	9.794	9.785	9.783	9.786	9.816	9.800	9.795
STD. ERROR	0.005	0.007	0.004	0.004	0.003	0.002	0.005	0.004	0.002	0.003	0.005	0.003	0.004
SULFITE B AXIS	10.683	10.690	10.683	10.665	10.665	10.662	10.670	10.661	10.666	10.677	10.649	10.674	10.674
STD. ERROR	0.005	0.006	0.004	0.004	0.004	0.003	0.006	0.005	0.002	0.004	0.005	0.003	0.005
SULFITE C AXIS	6.506	6.518	6.508	6.510	6.510	6.495	6.506	6.504	6.519	6.515	6.523	6.511	6.515
STD. ERROR	0.004	0.004	0.003	0.003	0.002	0.002	0.003	0.003	0.001	0.002	0.003	0.002	0.003
SCRUBBER OPERATIONAL PARAMETERS													
% SOLID OXIDATION	10.60	13.40	16.90	11.60	21.90	14.30	14.00	9.08	20.40	19.00	10.40	7.54	29.20
SAT. RATIO (RADIAN 50 C.)	0.19	0.39	0.32	0.10	0.67	0.26	0.83	1.12	1.11	1.15	0.95	0.69	1.12
STOIC. RATIO	1.63	1.25	1.49	1.06	1.22	1.43	0.98	1.14	1.32	1.13	1.05	1.27	1.06
SLURRY PH	5.82	5.66	6.15	5.25	5.95	6.02	5.49	5.79	5.74	5.48	5.49	5.81	5.16
SLURRY TEMPERATURE (C)	51.0	52.0	52.0	50.0	51.0	50.0	52.0	50.0	52.0	50.0	50.0	50.0	50.0
MAKE/PASS (MOLES/THOUS GAL)	86.6	88.6	99.1	63.6	84.0	84.1	64.5	64.0	75.5	56.7	71.9	96.0	56.0
LIQ/GAS (GAL/THOUS CFM)	40.0	40.2	39.5	40.2	41.2	40.9	41.1	39.1	40.2	41.0	41.1	41.1	41.0
WT % CL IN LIQUOR	0.30	0.25	0.17	0.21	0.29	0.24	0.17	0.20	0.31	0.39	0.32	0.34	0.24
WT % MG IN LIQUOR	0.04	0.44	0.04	0.03	0.05	0.05	0.05	0.05	0.04	0.06	0.06	0.05	0.04
HOLD TANK RES. TIME (MINS)	12.0	12.0	12.0	12.0	14.8	14.8	14.8	10.8	10.8	14.8	14.8	14.8	10.8

TABLE 1. TCA SLURRY ANALYSES

RUN NUMBER	581-2A	FACT.	FACT.	FACT.	FACT.	FACT.	FACT	FACT	FACT	FACT	583-2B	584-2A	584-2A
ANALYSIS POINT	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816
DATE	020876	021676	022276	030176	030776	031576	032276	033076	041276	042276	043076	050776	051476
TIME	0730	0730	0730	0730	0730	0730	0700	0730	0730	0730	0730	0730	0730
ADSORBENT	LS	LS	LS	LIME	LIME	LS	LS	LS	LS	LS	LS	LS	LS
ON-SITE SOLIDS ANALYSES													
ASH (WT %)	41.50	35.57	41.76	0.0	43.05	45.25	45.79	39.02	35.44	33.78	33.62	32.33	31.28
CA (WT %)	25.47	31.01	25.20	0.0	25.02	23.32	24.70	27.46	30.39	27.91	23.16	31.27	33.29
SO2 (WT %)	19.63	12.36	15.93	0.0	20.53	15.75	16.48	16.56	20.08	15.56	19.90	16.14	19.82
SO3 (WT %)	5.88	4.16	6.99	0.0	5.78	8.88	7.53	6.40	5.30	10.58	9.41	5.80	0.83
CO2 (WT %)	2.63	13.62	5.01	0.0	0.93	1.32	1.10	5.93	4.78	5.50	5.06	10.02	12.01
TVA SOLIDS CHARACTERIZATION													
ASH (WT %, ACID INSOLUBLE)	38.5	30.5	35.0	30.0	39.0	38.0	39.0	35.0	30.0	30.0	25.0	28.0	25.0
CACO3 (WT %, BY IR)	7.5	44.5	12.0	3.0	3.0	4.0	7.0	14.0	9.0	14.0	9.0	19.0	31.0
CASO3 X .5 H2O (WT %, IR)	46.0	25.0	42.6	57.0	49.0	46.0	40.0	41.0	51.0	44.0	53.0	45.0	37.0
CASO4 X 2H2O (WT %, IR)	8.0	0.0	10.4	10.0	9.0	12.0	14.0	10.0	10.0	12.0	13.0	9.0	7.0
SURFACE AREA (SQ M/GM)	4.9	3.8	2.4	5.0	7.3	4.2	5.3	4.2	3.3	5.3	4.6	3.5	4.1
TVA SLURRY CHARACTERIZATION													
SLURRY SOLIDS %	18.3	20.3	20.3	16.3	16.7	15.6	18.0	17.7	16.6	16.6	15.9	20.0	16.9
SETTLED % SOLIDS	45.6	55.6	55.6	46.4	42.6	40.4	47.7	48.1	47.9	35.6	34.4	41.6	38.1
SETTLED BULK DENSITY(GM/CC)	1.31	1.29	1.31	1.38	1.30	1.30	1.31	1.37	1.42	1.28	1.25	1.28	1.31
SETTLING RATE (CM/HR)	5.0	5.5	7.3	11.1	3.6	3.7	3.8	3.5	7.6	2.4	2.4	2.1	1.5
TVA CRYSTALLOGRAPHIC ANALYSES													
SULFITE REFRACTIVE INDEX	1.589	1.587	1.585	1.586	1.585	1.588	1.587	1.588	1.590	1.589	1.589	1.587	1.586
SULFITE A AXIS	9.793	9.762	9.788	9.775	9.772	9.791	9.774	9.791	9.787	9.799	9.794	9.803	9.788
STD. ERROR	0.004	0.003	0.003	0.004	0.002	0.002	0.003	0.001	0.002	0.003	0.004	0.003	0.003
SULFITE B AXIS	10.665	10.667	10.655	10.653	10.662	10.670	10.667	10.650	10.667	10.675	10.686	10.656	10.658
STD. ERROR	0.005	0.004	0.003	0.004	0.002	0.003	0.003	0.001	0.003	0.003	0.004	0.003	0.004
SULFITE C AXIS	6.512	6.508	6.512	6.507	6.504	6.510	6.521	6.522	6.517	6.504	6.514	6.499	6.529
STD. ERROR	0.003	0.002	0.002	0.003	0.001	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002
SCRUBBER OPERATIONAL PARAMETERS													
% SOLID OXIDATION	19.30	21.20	26.60	0.0	13.50	31.10	26.77	23.40	17.40	35.00	27.40	22.30	30.72
SAT. RATIO (RADIAN 50 C.)	1.24	1.14	1.28	0.0	1.42	1.13	1.57	1.02	0.93	1.22	1.12	0.34	1.05
STOIC. RATIO	1.20	2.26	1.33	0.0	1.14	1.16	1.25	1.45	1.42	1.33	1.17	1.71	1.85
SLURRY PH	0.0	5.82	5.67	0.0	5.73	5.03	5.24	5.53	5.83	5.41	5.33	5.71	5.28
SLURRY TEMPERATURE (C)	0.0	52.0	52.0	0.0	50.0	50.0	51.0	52.0	50.0	52.0	50.0	50.0	51.0
MAKE/PASS (MOLES/THOUS GAL)	73.3	73.1	68.4	55.7	54.4	37.6	50.1	82.4	78.7	80.1	94.7	96.4	83.5
LIQ/GAS (GAL/THOUS CFM)	40.3	24.9	36.2	48.5	47.3	48.3	48.4	30.7	36.6	41.7	41.3	40.6	40.8
WT % CL IN LIQUOR	0.48	0.61	0.65	0.0	0.78	0.88	1.39	1.61	0.98	0.48	0.35	0.44	0.81
WT % MG IN LIQUOR	0.05	0.05	0.04	0.0	0.04	0.04	0.23	1.04	0.45	0.68	0.58	1.07	1.26
HOLD TANK RES. TIME (MINS)	12.0	6.0	6.0	12.0	6.0	6.0	6.0	9.0	9.0	12.0	3.0	3.0	3.0

TABLE 1. TCA SLURRY ANALYSES

RUN NUMBER	586-2A	587-2A	587-2A	588-2A	589-2A	601-2A	601-2A	603-2A	604-2A	604-2A	605-2A	606-2A	607-2A
ANALYSIS POINT	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816
DATE	052276	060176	061076	061976	062876	070476	071076	072176	072976	080376	081276	081876	082376
TIME	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730
ADSORBENT	LS	LS	LS	LS	LS	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LIME
ON-SITE SOLIDS ANALYSES													
ASH (WT %)	46.32	52.77	40.82	39.27	36.93	38.82	50.47	55.49	46.14	33.19	28.24	53.08	45.10
CA (WT %)	24.50	26.62	26.76	29.03	27.04	26.92	20.73	18.63	23.12	25.15	29.75	20.33	23.60
SO2 (WT %)	17.37	8.68	10.47	9.91	18.03	22.99	19.92	17.73	18.53	18.88	28.23	18.36	18.08
SO3 (WT %)	2.36	0.01	10.69	5.71	6.82	5.76	3.93	3.69	7.13	13.64	6.64	3.94	7.44
CO2 (WT %)	6.16	12.04	5.99	12.55	5.67	0.57	0.56	0.49	0.05	0.27	0.46	0.43	0.65
TVA SOLIDS CHARACTERIZATION													
ASH (WT %, ACID INSOLUBLE)	40.0	45.0	33.0	30.0	30.0	30.0	35.0	45.0	30.0	40.0	25.0	45.0	35.0
CACO3 (WT %, BY IR)	16.0	33.0	3.0	36.0	11.0	0.0	5.0	0.0	0.0	0.0	4.0	1.0	3.0
CASO3 X .5 H2O (WT %, IR)	35.0	12.0	56.0	20.0	48.0	60.0	52.0	40.0	59.0	50.0	61.0	45.0	46.0
CASO4 X 2H2O (WT %, IR)	8.0	10.0	8.0	14.0	11.0	10.0	8.0	15.0	11.0	10.0	10.0	9.0	16.0
SURFACE AREA (SQ M/GM)	2.7	4.1	5.7	4.8	5.6	6.1	5.8	5.2	6.5	6.8	6.3	8.1	7.1
TVA SLURRY CHARACTERIZATION													
SLURRY SOLIDS %	15.6	10.5	10.1	15.2	15.1	9.5	9.5	9.2	8.5	10.1	7.7	8.5	9.1
SETTLED % SOLIDS	42.3	25.8	34.0	42.8	32.0	43.0	50.8	43.0	46.9	48.6	39.5	44.9	47.1
SETTLED BULK DENSITY(GM/CC)	1.31	1.17	1.28	1.36	1.26	1.30	1.22	1.35	1.34	1.27	1.30	1.32	1.33
SETTLING RATE (CM/HR)	3.5	2.5	5.6	3.0	2.4	42.6	50.0	3.4	32.2	33.2	30.9	42.6	32.6
TVA CRYSTALLOGRAPHIC ANALYSES													
SULFITE REFRACTIVE INDEX	1.589	1.589	1.587	1.587	1.588	1.574	1.574	1.586	1.585	1.580	1.587	1.590	1.586
SULFITE A AXIS	9.802	9.803	9.793	9.785	9.803	9.782	9.786	9.783	9.789	9.786	9.789	9.786	9.774
STD. ERROR	0.003	0.004	0.002	0.003	0.002	0.003	0.002	0.004	0.003	0.002	0.002	0.003	0.002
SULFITE B AXIS	10.663	10.649	10.677	10.668	10.667	10.675	10.679	10.691	10.671	10.688	10.656	10.683	10.694
STD. ERROR	0.003	0.004	0.003	0.004	0.002	0.003	0.002	0.004	0.003	0.002	0.003	0.003	0.002
SULFITE C AXIS	6.513	6.484	6.497	6.529	6.513	6.511	6.507	6.501	6.514	6.506	6.512	6.506	6.511
STD. ERROR	0.002	0.002	0.002	0.002	0.001	0.002	0.001	0.003	0.002	0.001	0.002	0.002	0.001
SCRUBBER OPERATIONAL PARAMETERS													
% SOLID OXIDATION	9.80	0.10	44.90	31.50	23.20	16.70	13.60	14.30	23.50	36.60	15.80	14.60	24.70
SAT. RATIO (RADIAN 50 C.)	0.71	0.16	1.43	1.15	1.06	0.79	0.93	0.83	0.83	0.94	0.33	0.86	0.93
STOIC. RATIO	1.45	3.49	1.60	2.28	1.31	1.11	1.02	1.02	1.08	0.96	1.01	1.07	1.12
SLURRY PH	5.16	5.94	4.98	5.43	5.32	6.04	7.07	6.64	6.82	6.94	0.0	7.93	7.90
SLURRY TEMPERATURE (C)	50.0	50.0	51.0	50.0	56.0	50.0	52.0	53.0	50.0	51.0	50.0	52.0	54.0
MAKE/PASS (MOLES/THOUS GAL)	58.7	86.0	90.9	55.0	97.6	72.6	63.2	57.4	120.5	104.0	10.3	106.3	95.3
LIQ/GAS (GAL/THOUS CFM)	40.0	40.0	41.0	60.1	40.7	41.6	45.5	40.9	31.6	30.8	60.2	30.9	30.7
WT % CL IN LIQUOR	0.39	0.03	0.20	0.51	0.14	0.11	0.16	0.29	0.35	0.30	0.28	0.27	0.25
WT % MG IN LIQUOR	0.82	0.75	1.02	1.13	1.11	0.15	0.27	0.30	0.34	0.30	0.33	0.32	0.51
HOLD TANK RES. TIME (MINS)	3.0	3.0	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	0.0	0.0

TABLE 1. TCA SLURRY ANALYSES

RUN NUMBER	608-2A	608-2A	609-2A	609-2A	610-2A	610-2A	611-2A	613-2A	614-2A	616-2A	616-2A	617-2A	701-2A
ANALYSIS POINT	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816
DATE	090476	090976	091576	092276	092976	100676	101076	102076	102776	110676	111176	111776	112676
TIME	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730
ADSORBENT	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LS
ON-SITE SOLIDS ANALYSES													
ASH (WT %)	34.47	34.17	47.22	34.87	40.10	50.89	38.38	42.50	39.34	51.44	42.90	40.69	5.19
CA (WT %)	26.97	27.42	24.09	26.79	26.79	22.48	24.95	23.13	27.62	22.32	23.20	25.27	43.10
SO2 (WT %)	24.61	25.69	22.57	24.81	27.03	22.44	16.64	15.56	25.41	20.45	19.45	22.44	36.55
SO3 (WT %)	6.53	5.38	2.08	6.81	1.48	0.88	12.19	11.24	2.89	1.50	7.59	5.22	5.06
CO2 (WT %)	1.15	1.43	0.75	0.41	0.76	0.47	0.60	0.77	0.83	1.43	0.89	1.26	3.91
TVA SOLIDS CHARACTERIZATION													
ASH (WT %, ACID INSOLUBLE)	35.0	30.0	45.0	45.0	25.0	35.0	35.0	40.0	30.0	38.0	40.0	25.0	5.0
CACO3 (WT %, BY IR)	2.0	3.0	0.0	1.0	3.0	2.0	3.0	0.0	0.0	6.0	2.0	5.0	18.0
CASO3 X .5 H2O (WT %, IR)	54.0	56.0	45.0	46.0	62.0	49.0	41.0	31.0	58.0	43.0	48.0	59.0	63.0
CASO4 X 2H2O (WT %, IR)	10.0	11.0	10.0	8.0	10.0	14.0	22.0	29.0	12.0	14.0	10.0	11.0	14.0
SURFACE AREA (SQ M/GM)	7.8	7.2	4.6	3.9	5.2	4.0	7.5	8.2	5.6	5.9	6.8	4.6	4.0
TVA SLURRY CHARACTERIZATION													
SLURRY SOLIDS %	16.3	16.2	10.9	7.9	7.8	7.7	9.0	9.2	7.9	9.1	7.8	20.2	7.6
SETTLED % SOLIDS	47.6	45.0	53.0	45.2	41.7	43.4	40.2	42.0	38.7	38.7	46.4	57.1	24.9
SETTLED BULK DENSITY(GM/CC)	1.38	1.37	1.33	1.38	1.36	1.33	1.33	1.33	1.29	1.31	1.35	1.36	1.19
SETTLING RATE (CM/HR)	37.2	8.6	26.9	52.6	52.1	67.2	39.2	34.8	36.6	33.8	67.8	9.4	5.4
TVA CRYSTALLOGRAPHIC ANALYSES													
SULFITE REFRACTIVE INDEX	1.581	1.585	1.587	1.582	1.585	1.582	1.583	1.581	1.587	1.582	1.585	0.0	0.0
SULFITE A AXIS	9.782	9.794	9.800	9.786	9.793	9.768	9.796	9.779	9.779	9.757	9.781	9.773	9.793
STD. ERROR	0.002	0.004	0.003	0.002	0.003	0.002	0.003	0.004	0.003	0.002	0.002	0.002	0.002
SULFITE B AXIS	10.675	10.664	10.674	10.652	10.666	10.665	10.677	10.676	10.675	10.670	10.660	10.653	10.663
STD. ERROR	0.002	0.004	0.003	0.002	0.003	0.002	0.004	0.004	0.003	0.003	0.002	0.002	0.002
SULFITE C AXIS	6.512	6.486	6.503	6.511	6.501	6.514	6.505	6.520	6.508	6.507	6.514	6.514	6.509
STD. ERROR	0.001	0.003	0.002	0.001	0.002	0.002	0.002	0.003	0.002	0.002	0.001	0.001	0.001
SCRUBBER OPERATIONAL PARAMETERS													
% SOLID OXIDATION	17.50	14.30	6.87	18.00	4.20	3.00	36.90	36.60	8.30	5.50	23.70	15.60	9.90
SAT. RATIO (RADIAN 50 C.)	1.11	0.08	0.18	0.55	0.12	0.82	0.95	0.88	0.80	0.89	1.29	1.06	0.81
STOIC. RATIO	1.03	1.04	1.14	1.01	1.08	1.10	1.07	1.07	1.14	1.17	1.03	1.08	1.21
SLURRY PH	7.85	7.96	6.99	6.84	7.68	7.95	8.08	6.74	8.08	8.32	5.74	8.00	5.64
SLURRY TEMPERATURE (C)	54.0	50.0	53.0	53.0	53.0	50.0	49.0	54.0	48.0	53.0	51.0	50.0	50.0
MAKE/PASS (MOLES/THOUS GAL)	124.8	127.7	132.9	103.1	117.6	103.4	102.5	87.8	123.3	74.9	76.8	80.9	72.3
LIQ/GAS (GAL/THOUS CFM)	30.5	30.4	30.8	31.2	31.0	30.6	30.8	41.5	31.0	40.8	40.8	40.6	40.2
WT % CL IN LIQUOR	0.25	0.28	0.36	0.34	0.30	0.41	0.55	0.58	0.44	0.25	0.47	0.39	0.35
WT % MG IN LIQUOR	0.50	0.52	0.38	0.33	0.33	0.35	0.43	0.44	0.35	0.02	0.03	0.05	0.02
HOLD TANK RES. TIME (MINS)	0.0	0.0	0.0	5.4	5.4	4.1	4.1	3.0	16.0	12.0	12.0	12.0	4.1

TABLE 1. TCA SLURRY ANALYSES

RUN NUMBER	701-2A	702-2A	703-2A	704-2A	704-2A	705-2A	705-2A	706-2A	706-1A	706-2A	TFG-2C	TFG-2D	TFG-2F
ANALYSIS POINT	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816	2816
DATE	113076	120976	121676	122376	123076	010777	011277	012277	012877	020377	021177	021877	022477
TIME	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730	0715	0715	0715
ADSORBENT	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS
ON-SITE SOLIDS ANALYSES													
ASH (WT %)	3.12	10.01	12.04	7.32	3.48	13.04	9.36	0.0	16.66	4.18	38.90	31.47	34.00
CA (WT %)	41.30	40.37	38.42	41.84	43.81	38.81	40.88	42.54	35.44	39.49	26.96	31.08	28.60
SO2 (WT %)	27.87	41.21	33.29	41.62	36.55	32.45	38.00	30.27	33.22	33.97	21.71	24.84	20.99
SO3 (WT %)	14.13	0.25	5.93	0.81	6.66	5.27	2.67	12.76	4.50	8.93	3.97	4.60	7.76
CO2 (WT %)	4.23	2.85	3.57	2.97	2.86	4.29	3.41	6.57	3.52	4.46	3.96	3.33	2.86
TVA SOLIDS CHARACTERIZATION													
ASH (WT %, ACID INSOLUBLE)	5.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	5.0	2.0	35.0	35.0	40.0
CACO3 (WT %, BY IR)	16.0	14.0	10.0	13.0	10.0	21.0	11.0	16.0	7.0	7.0	15.0	9.0	5.0
CASO3 X .5 H2O (WT %, IR)	60.0	71.0	80.0	73.0	77.0	63.0	82.0	68.0	80.0	75.0	38.0	45.0	48.0
CASO4 X 2H2O (WT %, IR)	19.0	14.0	11.0	14.0	13.0	13.0	6.0	16.0	8.0	16.0	11.0	10.0	8.0
SURFACE AREA (SQ M/GM)	5.2	2.1	2.2	2.4	2.4	2.3	1.8	2.9	2.6	2.9	3.7	3.5	5.0
TVA SLURRY CHARACTERIZATION													
SLURRY SOLIDS %	8.3	15.1	7.7	8.2	8.0	15.9	15.2	15.2	14.5	15.4	15.3	13.9	15.5
SETTLED % SOLIDS	24.4	41.4	33.1	33.7	37.5	38.9	41.6	39.0	37.6	35.8	40.7	40.2	36.3
SETTLED BULK DENSITY(GM/CC)	1.18	1.31	1.23	1.24	1.22	1.27	1.30	1.30	1.31	1.26	1.33	1.30	1.28
SETTLING RATE (CM/HR)	4.8	5.4	13.8	17.1	10.9	5.5	5.6	4.0	4.5	4.6	6.0	7.0	4.0
TVA CRYSTALLOGRAPHIC ANALYSES													
SULFITE REFRACTIVE INDEX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SULFITE A AXIS	9.781	9.794	9.791	9.794	9.773	9.791	9.788	9.792	9.778	9.783	9.784	9.794	9.799
STD. ERROR	0.002	0.002	0.002	0.003	0.004	0.002	0.002	0.002	0.002	0.003	0.002	0.002	0.003
SULFITE B AXIS	10.664	10.670	10.655	10.669	10.671	10.682	10.652	10.658	10.668	10.659	10.664	10.663	10.660
STD. ERROR	0.002	0.002	0.002	0.003	0.004	0.003	0.002	0.002	0.002	0.003	0.002	0.002	0.003
SULFITE C AXIS	6.514	6.493	6.502	6.496	6.502	6.507	6.500	6.512	6.513	6.519	6.517	6.508	6.517
STD. ERROR	0.001	0.001	0.001	0.002	0.002	0.002	0.001	0.001	0.001	0.002	0.001	0.001	0.002
SCRUBBER OPERATIONAL PARAMETERS													
% SOLID OXIDATION	20.00	0.40	12.40	1.50	11.80	11.50	5.30	25.20	9.70	10.80	12.70	12.90	22.80
SAT. RATIO (RADIAN 50 C.)	1.07	0.17	0.21	0.31	0.47	1.44	0.32	1.01	0.16	1.33	0.96	0.79	0.69
STOIC. RATIO	1.20	1.11	1.15	1.13	1.20	1.20	1.16	1.19	1.09	1.18	1.23	1.24	1.20
SLURRY PH	5.57	5.70	5.66	5.77	5.71	5.91	5.86	5.70	5.50	5.41	5.71	5.91	5.66
SLURRY TEMPERATURE (C)	53.0	50.0	49.0	50.0	52.0	50.0	50.0	47.0	53.0	48.0	50.0	49.0	53.0
MAKE/PASS (MOLES/THOUS GAL)	64.7	77.1	88.4	61.3	86.6	76.9	80.7	78.8	72.7	64.1	95.8	73.3	78.6
LIQ/GAS (GAL/THOUS CFM)	40.6	40.7	41.0	40.4	40.9	40.8	41.0	41.0	40.7	41.3	41.1	61.0	40.8
WT % CL IN LIQUOR	0.27	0.37	0.36	0.36	0.31	0.24	0.35	0.32	0.27	0.43	0.46	0.02	0.33
WT % MG IN LIQUOR	0.04	0.08	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.05	0.05
HOLD TANK RES. TIME (MINS)	4.1	0.0	0.0	0.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0

TABLE 1. TCA SLURRY ANALYSES

RUN NUMBER	TFG-2F	707-2A	709-2A	710-2A	711-2A
ANALYSIS POINT	2816	2816	2816	2816	2816
DATE	022877	030877	031677	032277	032877
TIME	0715	0715	0715	0715	0715
ADSORBENT	LS	LS	LS	LS	LS
ON-SITE SOLIDS ANALYSES					
ASH (WT %)	32.74	39.11	42.30	44.41	39.11
CA (WT %)	29.07	26.86	25.00	24.74	28.35
SO2 (WT %)	23.98	19.54	17.30	19.54	25.25
SO3 (WT %)	4.81	5.71	5.81	3.86	1.59
CO2 (WT %)	4.06	3.97	4.75	3.41	2.36
TVA SOLIDS CHARACTERIZATION					
ASH (WT %, ACID INSOLUBLE)	35.0	35.0	35.0	35.0	30.0
CACO3 (WT %, BY IR)	9.0	12.0	16.0	5.0	13.0
CASO3 X .5 H2O (WT %, IR)	46.0	42.0	38.0	50.0	45.0
CASO4 X 2H2O (WT %, IR)	10.0	11.0	11.0	10.0	12.0
SURFACE AREA (SQ M/GM)	4.7	4.4	2.7	3.8	3.1
TVA SLURRY CHARACTERIZATION					
SLURRY SOLIDS %	14.3	16.3	14.9	15.5	14.2
SETTLED % SOLIDS	35.9	41.6	44.5	41.6	40.5
SETTLED BULK DENSITY(GM/CC)	1.27	1.30	1.39	1.32	1.33
SETTLING RATE (CM/HR)	5.5	6.4	10.5	6.9	8.2
TVA CRYSTALLOGRAPHIC ANALYSES					
SULFITE REFRACTIVE INDEX	0.0	0.0	0.0	0.0	0.0
SULFITE A AXIS	9.793	9.796	9.808	9.781	9.782
STD. ERROR	0.004	0.003	0.002	0.002	0.002
SULFITE B AXIS	10.672	10.662	10.667	10.657	10.659
STD. ERROR	0.005	0.003	0.002	0.002	0.002
SULFITE C AXIS	6.511	6.520	6.516	6.521	6.512
STD. ERROR	0.003	0.002	0.002	0.001	0.001
SCRUBBER OPERATIONAL PARAMETERS					
% SOLID OXIDATION	13.80	18.90	19.30	13.60	4.80
SAT. RATIO (RADIAN 50 C.)	0.84	1.47	1.11	1.19	0.63
STOIC. RATIO	1.19	1.27	1.33	1.24	1.22
SLURRY PH	5.57	5.54	5.41	5.77	5.62
SLURRY TEMPERATURE (C)	50.0	50.0	50.0	53.0	51.0
MAKE/PASS (MOLES/THOUS GAL)	74.3	64.6	59.8	58.5	68.3
LIQ/GAS (GAL/THOUS CFM)	40.8	41.0	41.0	40.9	41.4
WT % CL IN LIQUOR	0.32	0.41	0.15	0.19	0.20
WT % MG IN LIQUOR	0.06	0.05	0.03	0.04	0.05
HOLD TANK RES. TIME (MINS)	12.0	4.1	4.1	10.0	12.0

TABLE 2. VENTURI/SPRAY TOWER SLURRY ANALYSES

RUN NUMBER	623-1A	623-1A	624-1A	624-1A	627-1A	628-1A	628-1B	628-1B	628-1B	701-1A	703-1A	703-1A	704-1A
ANALYSIS POINT	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816
DATE	031375	031475	040375	041175	080875	091475	092175	092875	100575	101275	102175	102875	110675
TIME	1300	1300	700	1145	1220	0700	0700	0700	0700	0700	0700	0900	0700
ADSORBENT	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LS	LS	LS	LS
ON-SITE SOLIDS ANALYSES													
ASH (WT %)	0.0	37.71	38.46	0.0	45.30	39.58	39.23	39.62	39.22	27.70	44.62	43.15	30.27
CA (WT %)	0.0	26.66	25.99	0.0	24.34	24.81	25.32	24.63	24.81	32.05	23.00	24.34	33.49
SO2 (WT %)	0.0	22.08	23.11	0.0	17.24	20.76	22.08	21.98	23.19	19.86	21.60	22.07	20.95
SO3 (WT %)	0.0	6.06	5.04	0.0	5.14	6.92	5.88	4.11	5.15	7.19	4.10	3.44	2.64
CO2 (WT %)	0.0	2.08	2.06	0.0	3.76	1.97	1.88	4.19	1.90	7.54	1.76	2.47	9.31
TVA SOLIDS CHARACTERIZATION													
ASH (WT %, ACID INSOLUBLE)	33.0	33.0	69.0	45.0	40.0	35.0	40.0	41.5	33.0	27.0	45.0	45.0	27.0
CACO3 (WT %, BY IR)	3.3	5.6	1.4	5.0	10.2	8.3	6.5	3.9	3.7	21.1	2.8	6.0	30.9
CASO3 X .5 H2O (WT %, IR)	59.0	53.0	27.0	45.0	38.4	43.3	47.6	44.8	53.1	44.8	45.0	41.0	34.8
CASO4 X 2H2O (WT %, IR)	4.5	9.0	2.0	7.2	11.4	13.4	5.8	9.8	10.2	7.1	7.2	8.0	7.3
SURFACE AREA (SQ M/GM)	7.0	5.9	4.6	3.0	8.1	4.1	4.3	5.1	4.1	3.4	2.2	1.8	2.5
TVA SLURRY CHARACTERIZATION													
SLURRY SOLIDS %	8.8	7.3	11.6	7.9	15.6	8.7	9.4	25.7	9.5	18.4	10.2	12.8	16.4
SETTLED % SOLIDS	38.1	32.2	39.1	46.4	34.0	44.9	39.6	42.1	44.5	37.0	44.7	45.5	42.2
SETTLED BULK DENSITY(GM/CC)	1.32	1.22	1.35	1.45	1.24	1.30	1.28	1.31	1.26	1.27	1.29	1.36	1.34
SETTLING RATE (CM/HR)	12.4	11.5	8.7	13.9	2.4	38.4	35.6	2.1	20.5	2.5	9.6	7.8	4.3
TVA CRYSTALLOGRAPHIC ANALYSES													
SULFITE REFRACTIVE INDEX	1.592	1.581	1.584	1.590	1.593	1.590	1.590	1.589	1.588	1.589	1.590	1.590	1.591
SULFITE A AXIS	9.743	9.750	9.759	9.799	9.769	9.776	9.775	9.764	9.778	9.798	9.769	9.799	9.795
STD. ERROR	0.010	0.012	0.019	0.035	0.003	0.006	0.006	0.010	0.003	0.005	0.006	0.006	0.006
SULFITE B AXIS	10.630	10.632	10.619	10.665	10.729	10.636	10.673	10.678	10.667	10.690	10.690	10.680	10.683
STD. ERROR	0.006	0.006	0.011	0.019	0.004	0.006	0.006	0.010	0.003	0.005	0.005	0.006	0.006
SULFITE C AXIS	6.502	6.495	6.493	6.498	6.510	6.531	6.521	6.514	6.518	6.506	6.519	6.527	6.511
STD. ERROR	0.005	0.005	0.010	0.018	0.004	0.005	0.005	0.007	0.003	0.004	0.004	0.005	0.005
SCRUBBER OPERATIONAL PARAMETERS													
% SOLID OXIDATION	0.0	18.00	14.80	0.0	19.30	21.00	17.60	13.00	15.10	22.40	13.20	11.10	9.20
SAT. RATIO (RADIAN 50 C.)	0.98	0.71	0.0	1.17	0.0	1.03	0.84	0.69	0.73	0.23	0.0	0.71	0.12
STOIC. RATIO	0.0	1.13	1.09	0.0	0.0	1.08	1.08	1.11	1.04	1.43	1.06	1.13	1.66
SLURRY PH	7.90	7.70	8.80	0.0	0.0	7.95	8.25	8.10	7.95	5.85	5.25	5.31	5.84
SLURRY TEMPERATURE (C)	51.0	50.0	50.0	0.0	0.0	52.0	53.0	50.0	52.0	54.0	50.0	51.0	52.0
MAKE/PASS (MOLES/THOUS GAL)	0.0	0.0	0.0	0.0	0.0	40.6	41.8	49.4	53.6	50.1	0.0	42.2	70.0
LIQ/GAS (GAL/THOUS CFM)	0.0	0.0	0.0	0.0	0.0	90.4	97.4	82.9	68.8	69.2	63.7	63.6	64.3
WT % CL IN LIQUOR	0.33	0.31	0.0	0.43	0.0	0.31	0.33	0.37	0.44	0.49	0.0	0.67	0.54
WT % MG IN LIQUOR	0.02	0.02	0.0	0.02	0.0	0.03	0.03	0.02	0.03	0.05	0.0	0.07	0.11
HOLD TANK RES. TIME (MINS)	17.0	17.0	17.0	17.0	20.0	12.0	12.0	12.0	12.0	20.0	20.0	20.0	20.0

LS = Limestone

TABLE 2. VENTURI/SPRAY TOWER SLURRY ANALYSES

RUN NUMBER	705-1A	706-1A	708-1A	709-1A	710-1A	710-1A	711-1B	713-1A		717-1A	FACT.	FACT.	FACT.
ANALYSIS POINT	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816
DATE	111376	111975	112775	120775	121475	122275	010176	010976	012276	013176	021576	022176	030276
TIME	0700	0700	0700	0700	0700	0700	0700	0700	0700	0730	0730	0730	0730
ADSORBENT	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LIME	LIME	LIME
ON-SITE SOLIDS ANALYSES													
ASH (WT %)	34.81	42.00	31.63	37.84	34.35	38.27	38.87	49.98	34.98	36.41	33.06	55.91	56.99
CA (WT %)	27.42	23.99	29.27	26.88	28.54	26.71	27.41	22.47	28.28	27.46	28.70	19.16	20.36
SO2 (WT %)	23.80	23.25	20.17	20.56	20.43	24.50	17.94	17.87	22.95	22.49	22.62	13.71	16.45
SO3 (WT %)	1.59	4.12	6.31	4.66	3.72	1.82	4.43	4.08	3.42	4.79	7.64	6.04	2.56
CO2 (WT %)	7.47	1.47	6.84	5.12	8.09	4.31	7.04	1.93	5.56	3.74	1.98	1.16	1.17
TVA SOLIDS CHARACTERIZATION													
ASH (WT %, ACID INSOLUBLE)	35.0	40.0	27.0	30.0	32.0	42.0	37.0	43.0	35.5	39.0	34.5	61.0	45.0
CACO3 (WT %, BY IR)	16.4	2.0	11.1	13.4	22.4	12.4	15.2	6.8	11.9	5.6	4.7	5.3	3.0
CASO3 X .5 H2O (WT %, IR)	40.1	48.1	54.1	47.5	39.5	41.5	39.1	41.9	44.7	50.3	53.8	27.7	40.0
CASO4 X 2H2O (WT %, IR)	8.4	10.0	7.8	9.1	6.1	9.1	8.7	8.3	7.9	5.1	7.0	6.0	13.0
SURFACE AREA (SQ M/GM)	1.8	2.2	2.2	2.5	2.3	1.9	3.1	2.9	3.1	2.3	5.2	5.0	5.0
TVA SLURRY CHARACTERIZATION													
SLURRY SOLIDS %	14.5	12.6	14.4	15.2	16.4	16.3	16.0	15.0	17.2	15.9	17.2	16.6	16.1
SETTLED % SOLIDS	50.3	40.6	44.6	43.5	43.5	43.2	40.8	41.8	41.6	42.7	50.9	55.6	46.9
SETTLED BULK DENSITY(GM/CC)	1.33	1.40	1.34	1.31	1.32	1.34	1.29	1.30	1.30	1.30	1.29	1.37	1.35
SETTLING RATE (CM/HR)	9.0	8.5	4.5	3.6	3.9	4.6	3.4	4.8	2.8	3.6	6.3	8.7	5.8
TVA CRYSTALLOGRAPHIC ANALYSES													
SULFITE REFRACTIVE INDEX	1.591	1.592	1.590	1.592	1.595	1.594	1.591	1.590	1.591	1.591	1.590	1.586	1.585
SULFITE A AXIS	9.781	9.790	9.790	9.785	9.797	9.788	9.800	9.791	9.795	9.806	9.786	9.774	9.773
STD. ERROR	0.005	0.010	0.003	0.002	0.003	0.002	0.004	0.002	0.003	0.003	0.003	0.004	0.004
SULFITE B AXIS	10.679	10.691	10.657	10.673	10.660	10.667	10.665	10.673	10.660	10.665	10.653	10.652	10.650
STD. ERROR	0.004	0.006	0.004	0.002	0.003	0.003	0.004	0.002	0.004	0.003	0.003	0.004	0.004
SULFITE C AXIS	6.509	6.534	6.503	6.505	6.492	6.501	6.515	6.519	6.517	6.511	6.450	6.501	6.511
STD. ERROR	0.003	0.005	0.002	0.001	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002
SCRUBBER OPERATIONAL PARAMETERS													
% SOLID OXIDATION	5.10	12.40	21.30	15.30	12.73	5.62	16.50	15.40	10.60	14.50	21.30	26.10	11.10
SAT. RATIO (RADIAN 50 C.)	0.25	1.11	0.57	0.57	0.15	0.23	0.90	1.17	1.11	0.64	0.54	1.22	1.19
STOIC. RATIO	1.25	1.03	1.30	1.26	1.39	1.18	1.46	1.21	1.26	1.19	1.14	1.18	1.23
SLURRY PH	6.00	5.25	5.85	5.71	6.03	5.83	5.57	5.14	5.50	5.53	7.93	8.13	8.18
SLURRY TEMPERATURE (C)	52.0	50.0	51.0	51.0	55.0	52.0	52.0	48.0	50.0	50.0	50.0	51.0	50.0
MAKE/PASS (MOLES/THOUS GAL)	61.1	47.1	47.5	53.0	63.3	63.9	58.3	49.6	52.5	53.8	41.0	33.2	68.6
LIQ/GAS (GAL/THOUS CFM)	67.0	63.9	63.9	63.9	63.1	64.1	63.7	64.2	65.6	64.1	85.0	43.6	5.3
WT % CL IN LIQUOR	0.34	0.37	0.45	0.42	0.37	0.37	0.56	0.55	0.44	0.34	0.49	0.88	1.22
WT % MG IN LIQUOR	0.06	0.07	0.09	0.09	0.08	0.09	0.07	0.08	0.48	0.43	0.05	0.04	0.06
HOLD TANK RES. TIME (MINS)	20.0	12.0	12.0	12.0	12.0	12.0	6.0	6.0	6.0	6.0	12.0	0.0	6.0

TABLE 2. VENTURI/SPRAY TOWER SLURRY ANALYSES

RUN NUMBER	FACT.	FACT.	FACT	FACT	FACT	FACT	629-1A	629-1A	630-1A	631-1A	632-1A	633-1A	634-1A
ANALYSIS POINT	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816
DATE	030676	031476	032076	040376	041476	042176	050176	050876	051576	052176	053176	060976	062076
TIME	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730
ADSORBENT	LS	LS	LS	LS	LS	LS	LIME	LIME	LIME	LIME	LIME	LIME	LIME
ON-SITE SOLIDS ANALYSES													
ASH (WT %)	41.73	38.58	39.30	36.78	25.60	33.37	28.04	30.71	40.73	31.88	46.19	36.96	18.26
CA (WT %)	27.58	28.08	26.08	29.13	30.65	29.98	28.11	28.34	24.25	27.60	23.54	26.38	34.19
SO2 (WT %)	19.19	16.84	18.76	17.42	24.44	19.36	25.91	25.54	22.38	26.78	22.44	23.98	28.77
SO3 (WT %)	2.95	5.58	6.36	6.83	4.88	5.43	9.64	7.39	6.27	6.59	3.26	5.88	6.32
CO2 (WT %)	5.37	6.64	4.24	5.31	7.93	7.09	0.19	0.19	0.55	0.44	0.49	1.06	5.33
TVA SOLIDS CHARACTERIZATION													
ASH (WT %, ACID INSOLUBLE)	33.0	30.0	35.0	38.0	20.0	30.0	30.0	35.0	30.0	35.0	40.0	30.0	2.0
CACO3 (WT %, BY IR)	13.0	19.0	31.0	10.0	16.0	14.0	0.0	1.0	0.0	1.0	2.0	2.0	20.0
CASO3 X .5 H2O (WT %, IR)	43.0	39.0	22.0	42.0	56.0	44.0	59.0	57.0	70.0	58.0	51.0	58.0	58.0
CASO4 X 2H2O (WT %, IR)	11.0	12.0	12.0	10.0	8.0	12.0	11.0	7.0	0.0	6.0	6.0	10.0	20.0
SURFACE AREA (SQ M/GM)	5.3	3.5	3.3	3.1	4.8	3.5	7.6	5.0	3.8	5.4	4.5	5.8	5.9
TVA SLURRY CHARACTERIZATION													
SLURRY SOLIDS %	15.5	16.7	15.3	18.7	20.7	16.5	10.0	8.6	9.5	9.6	8.4	8.7	5.8
SETTLED % SOLIDS	44.4	45.4	45.6	50.9	27.9	43.1	43.2	50.3	46.7	46.7	44.2	39.7	55.7
SETTLED BULK DENSITY(GM/CC)	1.35	1.33	1.33	1.36	1.21	1.35	1.35	1.34	1.33	1.31	1.29	1.29	1.46
SETTLING RATE (CM/HR)	4.1	4.4	3.4	3.3	2.6	3.0	10.0	17.3	14.3	19.3	19.6	13.8	100.2
TVA CRYSTALLOGRAPHIC ANALYSES													
SULFITE REFRACTIVE INDEX	1.585	1.588	1.590	1.587	1.589	1.592	1.585	1.586	1.591	1.592	1.588	1.591	1.594
SULFITE A AXIS	9.790	9.786	9.797	9.798	9.797	9.796	9.793	9.786	9.797	9.794	9.795	9.791	9.795
STD. ERROR	0.004	0.002	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.004
SULFITE B AXIS	10.665	10.654	10.674	10.656	10.648	10.658	10.675	10.663	10.669	10.659	10.681	10.669	10.615
STD. ERROR	0.004	0.002	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.004
SULFITE C AXIS	6.492	6.515	6.496	6.523	6.498	6.513	6.515	6.511	6.504	6.497	6.497	6.500	6.488
STD. ERROR	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
SCRUBBER OPERATIONAL PARAMETERS													
% SOLID OXIDATION	10.10	20.95	21.30	23.90	13.70	18.30	22.90	13.20	18.30	16.40	10.40	16.40	14.90
SAT. RATIO (RADIAN SO C.)	1.33	1.21	1.23	1.03	0.51	1.10	0.45	0.46	0.25	0.09	0.17	0.14	1.40
STOIC. RATIO	1.46	1.51	1.25	1.43	1.23	1.44	0.95	0.99	1.01	0.98	1.07	1.05	1.15
SLURRY PH	5.78	5.79	6.73	5.46	5.39	5.70	6.04	6.04	6.17	6.95	7.04	7.08	8.12
MAKE/PASS (MOLES/THOUS GAL)	79.4	66.4	53.0	56.9	74.2	98.4	59.7	59.1	56.3	81.2	51.4	55.6	29.0
LIQ/GAS (GAL/THOUS CFM)	44.2	33.1	30.0	46.7	61.7	23.4	63.9	64.2	63.7	43.6	44.7	62.8	63.5
WT % CL IN LIQUOR	1.36	1.30	0.0	1.67	0.91	0.45	0.34	0.35	0.55	0.57	0.71	0.50	2.13
WT % MG IN LIQUOR	0.06	0.05	0.0	1.02	1.24	0.77	0.45	0.33	0.41	0.45	0.48	0.44	0.03
HOLD TANK RES. TIME (MINS)	12.0	6.0	4.5	9.5	9.5	0.0	3.0	3.0	3.0	3.0	3.0	3.0	12.0

TABLE 2. VENTURI/SPRAY TOWER SLURRY ANALYSES

RUN NUMBER	634-1A	718-1A	718-1A	635-1A	635-1A	636-1A	637-1A	638-1A	639-1A	640-1A	641-1A	642-1A	642-1A
ANALYSIS POINT	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816
DATE	062776	070376	071176	072076	072676	080176	081176	081776	082576	090576	091076	091676	092376
TIME	0730	0800	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730
ADSORBENT	LIME	LIME	LS	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LIME
ON-SITE SOLIDS ANALYSES													
ASH (WT %)	2.44	4.60	0.0	10.90	0.0	2.23	0.41	0.0	0.0	3.12	0.0	14.17	1.97
CA (WT %)	40.97	38.71	47.23	39.53	42.41	42.72	44.80	40.36	41.02	41.69	45.37	36.14	41.40
SO2 (WT %)	34.54	25.00	31.12	34.69	28.15	35.47	37.39	36.54	41.98	38.62	39.42	36.73	37.82
SO3 (WT %)	10.23	19.04	17.05	4.76	19.35	8.84	8.21	10.91	7.05	7.46	12.47	5.40	9.37
CO2 (WT %)	2.82	1.47	5.50	3.82	2.94	2.80	1.87	2.44	2.10	1.14	1.52	0.32	0.64
TVA SOLIDS CHARACTERIZATION													
ASH (WT %, ACID INSOLUBLE)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
CACO3 (WT %, BY IR)	8.0	6.0	14.0	10.0	9.0	12.0	7.0	7.0	5.0	4.0	2.0	1.0	2.0
CASO3 X .5 H2O (WT %, IR)	80.0	66.0	66.0	83.0	78.0	75.0	83.0	80.0	88.0	82.0	86.0	88.0	84.0
CASO4 X 2H2O (WT %, IR)	12.0	28.0	20.0	7.0	13.0	13.0	11.0	13.0	7.0	14.0	12.0	12.0	14.0
SURFACE AREA (SQ M/GM)	7.1	4.4	4.6	10.4	7.4	10.3	6.3	5.6	8.9	5.4	5.6	5.0	4.6
TVA SLURRY CHARACTERIZATION													
SLURRY SOLIDS %	4.5	4.5	9.2	9.4	9.0	10.3	8.6	5.0	5.5	10.8	8.3	8.2	8.1
SETTLED % SOLIDS	40.6	37.2	30.9	36.0	36.6	42.4	39.6	40.7	37.8	53.9	41.9	40.8	40.2
SETTLED BULK DENSITY(GM/CC)	1.21	1.31	1.22	1.19	1.31	1.21	1.25	1.30	1.22	1.31	1.25	1.30	1.29
SETTLING RATE (CM/HR)	90.0	67.7	4.6	8.4	10.9	8.7	28.2	87.0	46.1	31.3	34.9	22.3	32.2
TVA CRYSTALLOGRAPHIC ANALYSES													
SULFITE REFRACTIVE INDEX	1.595	1.593	1.586	1.580	1.582	1.585	1.584	1.600	1.590	1.583	1.580	1.585	1.582
SULFITE A AXIS	9.764	9.766	9.792	9.767	9.774	9.736	9.773	9.772	9.797	9.791	9.781	9.788	9.789
STD. ERROR	0.002	0.002	0.003	0.002	0.002	0.002	0.003	0.003	0.002	0.003	0.003	0.003	0.002
SULFITE B AXIS	10.656	10.670	10.675	10.633	10.645	10.663	10.653	10.646	10.647	10.672	10.662	10.659	10.666
STD. ERROR	0.002	0.002	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.002
SULFITE C AXIS	6.508	6.502	6.506	6.510	6.504	6.511	6.513	6.515	6.495	6.513	6.511	6.514	6.511
STD. ERROR	0.001	0.001	0.002	0.001	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.001
SCRUBBER OPERATIONAL PARAMETERS													
% SOLID OXIDATION	19.10	37.80	30.40	9.80	35.40	16.60	14.90	19.20	11.80	13.30	20.20	10.50	16.50
SAT. RATIO (RADIAN 50 C.)	1.19	1.09	1.16	0.44	1.00	0.99	0.97	1.18	0.05	0.75	0.36	0.61	0.84
STOIC. RATIO	1.09	1.09	1.20	1.17	1.11	1.14	1.08	1.01	0.98	1.06	1.04	1.01	1.04
SLURRY PH	7.94	5.33	5.87	8.65	7.95	7.87	7.96	7.91	6.99	6.87	7.04	6.55	6.94
SLURRY TEMPERATURE (C)	53.0	50.0	53.0	52.0	53.0	50.0	50.0	52.0	54.0	54.0	54.0	53.0	52.0
MAKE/PASS (MOLES/THOUS GAL)	39.8	22.6	38.7	37.6	44.1	36.2	37.7	42.8	44.4	51.4	48.6	61.4	60.2
LIQ/GAS (GAL/THOUS CFM)	64.0	111.0	63.0	63.1	63.5	89.3	74.3	63.7	63.7	64.3	45.1	34.9	34.8
WT % CL IN LIQUOR	0.37	0.44	0.48	0.42	0.45	0.44	0.36	0.29	0.35	0.34	0.55	0.54	0.64
WT % MG IN LIQUOR	0.06	0.04	0.06	0.05	0.07	0.07	0.06	0.06	0.28	0.30	0.40	0.36	0.44
HOLD TANK RES. TIME (MINS)	12.0	12.0	12.0	12.0	12.0	12.0	12.0	3.0	3.0	3.0	3.0	3.0	3.0

TABLE 2. VENTURI/SPRAY TOWER SLURRY ANALYSES

RUN NUMBER	643-1A	643-1A	VFG-001	VFG-1B	VFG-1B	VFG-1D	VFG-1F	VFG-1F	VFG-1I	VFG-1P	801-1A	801-1A	802-1A
ANALYSIS POINT	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816	1816
DATE	092876	100476	101176	102176	102876	110576	111276	111676	112576	120176	010877	011177	012777
TIME	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730	0730
ADSORBENT	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LIME	LS	LS	LS
ON-SITE SOLIDS ANALYSES													
ASH (WT %)	0.0	0.0	38.99	16.39	11.14	39.92	54.12	63.83	41.36	48.44	10.12	2.69	8.06
CA (WT %)	43.71	42.74	26.67	37.41	40.42	28.19	19.86	16.90	25.61	23.74	42.48	42.71	40.73
SO2 (WT %)	39.09	40.05	25.69	35.65	37.06	25.15	16.29	16.28	21.17	19.90	33.08	34.02	30.40
SO3 (WT %)	13.19	11.30	3.80	1.28	3.53	0.93	4.39	0.32	5.38	2.77	2.77	7.83	7.11
CO2 (WT %)	1.33	0.95	0.19	4.12	2.26	2.75	1.48	0.82	1.70	1.92	6.92	5.17	6.42
TVA SOLIDS CHARACTERIZATION													
ASH (WT %, ACID INSOLUBLE)	1.0	1.0	30.0	1.0	1.0	30.0	56.0	35.0	30.0	35.0	0.0	0.0	5.0
CACO3 (WT %, BY IR)	4.0	4.0	2.0	14.0	6.0	8.0	4.0	4.0	9.0	6.0	19.0	12.0	14.0
CASO3 X .5 H2O (WT %, IR)	85.0	83.0	54.0	77.0	82.0	54.0	32.0	51.0	49.0	49.0	67.0	77.0	70.0
CASO4 X 2H2O (WT %, IR)	11.0	12.0	15.0	9.0	12.0	8.0	8.0	10.0	12.0	10.0	14.0	12.0	11.0
SURFACE AREA (SQ M/GM)	6.1	3.8	5.2	5.8	5.9	6.5	2.6	8.1	4.6	4.9	3.2	2.8	4.5
TVA SLURRY CHARACTERIZATION													
SLURRY SOLIDS %	8.7	9.1	9.1	8.6	8.4	9.6	7.5	16.0	15.0	8.3	6.3	6.3	5.2
SETTLED % SOLIDS	37.1	31.0	43.5	48.6	40.6	43.4	51.0	45.5	44.1	47.5	25.9	27.8	23.4
SETTLED BULK DENSITY(GM/CC)	1.22	1.21	1.32	1.41	1.28	1.31	1.45	1.36	1.34	1.41	1.15	1.15	1.17
SETTLING RATE (CM/HR)	6.3	4.6	22.2	86.4	37.0	27.4	88.2	5.2	7.5	73.2	6.8	8.8	7.5
TVA CRYSTALLOGRAPHIC ANALYSES													
SULFITE REFRACTIVE INDEX	1.587	1.587	1.590	1.587	1.581	1.582	1.580	0.0	0.0	0.0	0.0	0.0	0.0
SULFITE A AXIS	9.776	9.792	9.791	9.751	9.766	9.757	9.778	9.779	9.750	9.757	9.788	9.793	9.791
STD. ERROR	0.002	0.002	0.004	0.002	0.002	0.003	0.002	0.004	0.004	0.002	0.002	0.002	0.002
SULFITE B AXIS	10.654	10.646	10.673	10.636	10.650	10.634	10.653	10.657	10.640	10.657	10.664	10.661	10.657
STD. ERROR	0.002	0.002	0.004	0.003	0.003	0.003	0.002	0.004	0.004	0.002	0.002	0.002	0.002
SULFITE C AXIS	6.501	6.499	6.510	6.498	6.510	6.489	6.501	6.511	6.510	6.502	6.506	6.506	6.517
STD. ERROR	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.001	0.001	0.001	0.001
SCRUBBER OPERATIONAL PARAMETERS													
% SOLID OXIDATION	21.20	18.40	10.50	2.80	7.11	4.10	17.70	4.30	16.90	10.00	6.20	15.50	15.70
SAT. RATIO (RADIAN 50 C.)	0.13	0.08	0.29	0.70	1.16	0.29	1.07	1.06	0.59	0.58	0.58	0.56	1.19
STOIC. RATIO	1.00	0.99	1.06	1.16	1.16	1.22	1.14	1.13	1.14	1.22	1.37	1.21	1.28
SLURRY PH	7.12	6.96	6.94	7.79	7.85	7.93	7.98	7.03	8.06	8.04	5.95	5.74	5.76
SLURRY TEMPERATURE (C)	53.0	53.0	54.0	54.0	50.0	48.0	52.0	50.0	52.0	53.0	51.0	48.0	53.0
MAKE/PASS (MOLES/THOUS GAL)	52.5	53.1	51.7	47.5	51.1	38.5	59.7	54.0	50.8	60.8	39.7	37.8	50.2
LIQ/GAS (GAL/THOUS CFM)	63.8	64.1	64.1	64.5	63.8	112.2	22.9	23.4	64.2	44.9	77.6	76.9	83.1
WT % CL IN LIQUOR	0.45	0.49	0.37	0.04	0.36	0.38	0.41	0.43	0.40	0.35	0.11	0.12	0.17
WT % MG IN LIQUOR	0.44	0.43	0.28	0.02	0.05	0.06	0.05	0.04	0.07	0.06	0.03	0.04	0.04
HOLD TANK RES. TIME (MINS)	3.0	3.0	3.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	18.0	18.0	18.0

TABLE 2. VENTURI/SPRAY TOWER SLURRY ANALYSES

RUN NUMBER	802-1A	802-1A	802-1A	803-1A	803-1A	805-1A	805-1A	806-1A	806-1A	806-1C	806-1C	807-1A	807-1A
ANALYSIS POINT	1815	1816	1815	1816	1815	1816	1815	1816	1815	1816	1815	1816	1815
DATE	012777	020477	020477	021077	021077	021977	021977	022577	022577	030177	030177	030577	030577
TIME	0730	0730	0730	0715	0715	0715	0715	0715	0715	0715	0715	0715	0715
ADSORBENT	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS
ON-SITE SOLIDS ANALYSES													
ASH (WT %)	63.29	6.37	57.58	3.02	77.05	6.51	56.84	6.34	66.43	7.92	65.99	7.92	44.31
CA (WT %)	12.21	41.00	13.49	43.87	8.09	44.31	15.33	41.22	10.95	41.62	11.63	43.58	24.21
SO2 (WT %)	0.36	28.00	0.33	27.14	0.18	25.52	0.0	28.95	0.36	30.89	0.0	31.82	21.29
SO3 (WT %)	16.56	7.18	19.19	8.35	9.45	5.18	18.62	8.98	14.97	4.06	15.38	1.21	3.92
CO2 (WT %)	0.22	10.28	0.59	10.72	1.04	13.42	1.21	7.04	0.49	9.65	0.33	11.14	1.90
TVA SOLIDS CHARACTERIZATION													
ASH (WT %, ACID INSOLUBLE)	45.0	2.0	45.0	2.0	40.0	2.0	43.0	10.0	45.0	0.0	35.0	0.0	35.0
CACO3 (WT %, BY IR)	0.0	23.0	0.0	34.0	0.0	53.0	0.0	17.0	0.0	24.0	0.0	35.0	5.0
CASO3 X .5 H2O (WT %, IR)	0.0	65.0	0.0	53.0	0.0	35.0	0.0	67.0	0.0	68.0	0.0	58.0	44.0
CASO4 X 2H2O (WT %, IR)	55.0	10.0	55.0	11.0	60.0	10.0	57.0	7.0	55.0	7.0	65.0	6.0	16.0
SURFACE AREA (SQ M/GM)	2.9	3.7	8.3	3.8	1.9	3.9	3.2	2.1	3.5	2.6	2.0	1.7	4.8
TVA SLURRY CHARACTERIZATION													
SLURRY SOLIDS %	15.5	5.9	15.6	5.6	16.0	13.0	15.5	15.9	18.2	15.1	17.4	17.0	14.6
SETTLED % SOLIDS	61.1	26.2	62.7	26.3	64.4	34.9	64.3	43.2	62.8	40.7	64.6	49.3	53.4
SETTLED BULK DENSITY(GM/CC)	1.55	1.16	1.54	1.17	1.62	1.26	1.68	1.33	1.59	1.33	1.65	1.40	1.49
SETTLING RATE (CM/HR)	42.9	8.7	53.3	9.1	53.5	3.6	46.7	6.4	35.0	4.6	36.9	9.2	20.3
TVA CRYSTALLOGRAPHIC ANALYSES													
SULFITE REFRACTIVE INDEX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SULFITE A AXIS	0.0	9.789	0.0	9.795	0.0	9.779	0.0	9.781	0.0	9.782	0.0	9.794	9.766
STD. ERROR	0.0	0.003	0.0	0.002	0.0	0.001	0.0	0.001	0.0	0.003	0.0	0.003	0.003
SULFITE B AXIS	0.0	10.664	0.0	10.660	0.0	10.656	0.0	10.659	0.0	10.663	0.0	10.675	10.670
STD. ERROR	0.0	0.003	0.0	0.002	0.0	0.001	0.0	0.002	0.0	0.003	0.0	0.003	0.003
SULFITE C AXIS	0.0	6.521	0.0	6.515	0.0	6.513	0.0	6.496	0.0	6.499	0.0	6.478	6.500
STD. ERROR	0.0	0.002	0.0	0.001	0.0	0.001	0.0	0.001	0.0	0.002	0.0	0.002	0.002
SCRUBBER OPERATIONAL PARAMETERS													
% SOLID OXIDATION	97.30	17.00	97.80	19.70	97.60	14.90	99.99	19.80	97.00	9.50	99.99	2.90	12.80
SAT. RATIO (RADIAN 50 C.)	1.01	1.05	1.04	1.11	1.04	0.37	0.98	0.12	0.88	0.21	1.12	0.08	1.47
STOIC. RATIO	1.02	0.38	0.98	1.48	1.19	1.82	1.17	1.30	1.01	1.39	1.07	1.48	1.13
SLURRY PH	5.04	5.58	4.85	5.67	4.81	6.04	4.95	6.24	4.54	6.15	4.56	6.29	4.53
SLURRY TEMPERATURE (C)	53.0	51.0	51.0	50.0	50.0	51.0	50.0	52.0	53.0	50.0	50.0	50.0	50.0
MAKE/PASS (MOLES/THOUS GAL)	50.2	20.9	20.9	32.9	32.9	36.6	36.6	34.5	34.5	35.3	35.3	38.1	38.1
LIQ/GAS (GAL/THOUS CFM)	83.1	82.3	82.3	90.5	90.5	91.1	91.1	92.1	92.1	91.1	91.1	91.5	91.5
WT % CL IN LIQUOR	0.34	0.26	0.45	0.30	0.46	0.26	0.60	0.12	0.62	0.10	0.54	0.05	0.45
WT % MG IN LIQUOR	0.07	0.06	0.09	0.05	0.08	0.06	0.11	0.04	0.13	0.04	0.12	0.03	0.10
HOLD TANK RES. TIME (MINS)	17.0	18.0	17.0	18.0	11.3	18.0	17.0	18.0	11.3	18.0	11.3	18.0	17.0

TABLE 2. VENTURI/SPRAY TOWER SLURRY ANALYSES

RUN NUMBER	851-1A	851-1A	853-1A	853-1A	854-1A	854-1A
ANALYSIS POINT	1816	1815	1816	1815	1816	1815
DATE	031577	031577	032377	032377	032977	032977
TIME	0715	0715	0715	0715	0715	0715
ADSORBENT	LIME	LIME	LIME	LIME	LIME	LIME
ON-SITE SOLIDS ANALYSES						
ASH (WT %)	0.0	53.17	6.46	58.26	12.24	47.37
CA (WT %)	45.41	16.51	44.89	14.66	40.96	16.77
SO2 (WT %)	35.44	0.36	35.47	0.72	36.30	1.31
SO3 (WT %)	10.11	20.95	4.90	18.08	2.27	23.34
CO2 (WT %)	3.14	0.11	3.35	0.44	3.47	0.37
TVA SOLIDS CHARACTERIZATION						
ASH (WT %, ACID INSOLUBLE)	0.0	40.0	0.0	25.0	0.0	25.0
CACO3 (WT %, BY IR)	12.0	0.0	12.0	0.0	17.0	0.0
CASO3 X .5 H2O (WT %, IR)	79.0	0.0	81.0	0.0	72.0	6.0
CASO4 X 2H2O (WT %, IR)	9.0	60.0	7.0	75.0	17.0	69.0
SURFACE AREA (SQ M/GM)	13.2	5.5	11.8	4.0	6.0	3.9
TVA SLURRY CHARACTERIZATION						
SLURRY SOLIDS %	6.5	17.8	6.7	19.4	7.5	18.5
SETTLED % SOLIDS	19.0	64.9	19.5	65.1	25.6	48.4
SETTLED BULK DENSITY(GM/CC)	1.11	1.65	1.12	1.64	1.16	1.38
SETTLING RATE (CM/HR)	3.7	32.2	6.0	53.4	7.0	6.9
TVA CRYSTALLOGRAPHIC ANALYSES						
SULFITE REFRACTIVE INDEX	0.0	0.0	0.0	0.0	0.0	0.0
SULFITE A AXIS	9.749	0.0	9.735	0.0	9.784	9.763
STD. ERROR	0.002	0.0	0.003	0.0	0.004	0.005
SULFITE B AXIS	10.638	0.0	10.643	0.0	10.629	10.642
STD. ERROR	0.003	0.0	0.003	0.0	0.004	0.005
SULFITE C AXIS	6.500	0.0	6.510	0.0	6.480	6.501
STD. ERROR	0.002	0.0	0.002	0.0	0.002	0.003
SCRUBBER OPERATIONAL PARAMETERS						
% SOLID OXIDATION	18.58	97.90	9.90	95.20	4.72	93.70
SAT. RATIO (RADIAN 50 C.)	0.59	0.97	0.75	0.97	0.35	1.03
STOIC. RATIO	1.06	1.01	1.30	1.10	0.0	0.0
SLURRY PH	7.65	4.11	8.21	5.37	7.94	4.91
SLURRY TEMPERATURE (C)	52.0	51.0	50.0	50.0	53.0	51.0
MAKE/PASS (MOLES/THOUS GAL)	35.9	35.9	39.1	39.1	37.1	37.1
LIQ/GAS (GAL/THOUS CFM)	94.2	94.2	89.2	89.2	90.4	90.4
WT % CL IN LIQUOR	0.25	0.38	0.27	0.45	0.30	0.36
WT % MG IN LIQUOR	0.07	0.12	0.09	0.16	0.09	0.12
HOLD TANK RES. TIME (MINS)	18.0	11.3	18.0	11.3	18.0	11.3

TABLE 3. SETTLING RATE DETERMINATIONS

Sample ID		Settling rate (cm/h) Muscle Shoals (M)	Shawnee (S)	S-M = Y	Y^2
1816	7/18/75	37.9	52.5	14.6	213.2
1816	7/24/75	34.2	47.5	13.3	176.9
1816	8/04/75	46.0	46.9	0.9	0.8
1816	8/18/75	5.4	5.5	0.1	0.0
1816	9/02/75	34.5	32.0	-2.5	6.3
1816	9/30/75	19.0	17.6	-1.4	2.0
1816	10/15/75	4.4	4.0	-0.4	0.2
1816	11/04/75	9.6	13.1	3.5	12.3
1816	11/13/75	8.8	9.3	0.5	0.3
1816	11/19/75	9.2	11.2	2.0	4.0
1816	12/17/75	4.1	4.1	0.0	0.0
1816	12/30/75	4.4	4.3	-0.1	0.0
1816	5/04/76	5.9	6.7	0.8	0.6
1816	5/17/76	16.4	22.0	5.6	31.4
1816	6/21/76	107.1	160.0	52.9	2798.4
2816	8/01/75	5.8	5.7	-0.1	0.0
2816	8/26/75	4.5	5.5	1.0	1.0
2816	10/08/75	5.5	5.6	0.1	0.0
2816	11/26/75	9.1	10.1	1.0	1.0
2816	12/03/75	6.2	5.4	-0.8	0.6
2816	1/07/76	7.0	7.0	0.0	0.0
2816	1/19/76	6.8	7.0	0.2	0.0
2816	4/27/76	2.7	2.7	0.0	0.0
2816	5/12/76	1.2	1.7	0.5	0.3
2816	5/24/76	3.9	4.4	0.5	0.3
2816	6/02/76	2.0	3.5	1.5	2.3
Total		401.6	495.3	93.7	3251.61
Mean		15.45	19.05	3.60	-
Std. Dev.		-	-	10.80	-

TABLE 4. TEMPERATURE OF DEHYDRATION OF $CaSO_3 \cdot 0.5H_2O$ IN DRIED SCRUBBER SOLIDS

Sample	Temp. °K	Std. Dev.[a]	Sample	Temp. °K	Std. Dev.[a]
Analysis Point 1816 (Venturi/spray tower)					
3-20-76	660	4.0	7-20-76	646	0.5
4-03-76	654	2.3	7-22-76	652	0.6
4-14-76	664	2.5	7-24-76	647	1.0
4-21-76	659	7.3	7-26-76	644	2.0
5-01-76	650	1.2	7-30-76	650	0.6
5-08-76	656	0.0	8-01-76	640	1.0
5-15-76	661	1.5	8-07-76	651	1.5
5-21-76	658	2.3	8-09-76	647	0.0
5-31-76	658	1.5	8-11-76	651	1.5
6-09-76	658	0.6	8-17-76	655	1.2
6-20-76	631	0.6	8-20-76	650	2.6
6-21-76	650	1.5	8-22-76	646	0.6
6-23-76	641	1.7	8-25-76	651	0.6
6-25-76	646	1.4	8-26-76	650	0.6
6-27-76	646	0.8	8-27-76	652	1.5
7-01-76	645	1.5	8-28-76	650	1.0
7-03-76	645	5.9	8-29-76	649	2.9
7-07-76	655	2.1	8-30-76	649	0.6
7-09-76	648	1.5	9-05-76	654	2.6
7-11-76	647	14.2	9-10-76	641	4.6
7-12-76	649	1.5	9-16-76	633	4.9
7-15-76	655	1.7	9-23-76	655	0.0
7-17-76	648	2.6	9-28-76	653	19.1
Analysis Point 2816 (TCA)					
3-22-76	658	1.0	5-14-76	658	1.0
3-30-76	643	3.4	5-22-76	656	6.1
4-12-76	660	0.6	6-01-76	654	1.0
4-22-76	658	1.0	6-10-76	657	0.6
4-30-76	655	3.5	6-19-76	654	0.6
5-07-76	657	0.6			

[a]Std. deviation calculated from 3 observations each sample.

TABLE 5. ANALYTICAL RESULTS FOR GYPSUM DETERMINATION BY DIFFERENTIAL SCANNING CALORIMETRY

Gypsum, % (wt) Known	Gypsum, % (wt) Found	Std. dev.	Coeff. var.
10.00	9.82	0.30	3.05
7.00	6.90	0.30	4.34
4.00	3.94	0.18	4.57
1.000	0.982	0.046	4.68
0.600	0.585	0.028	4.79
0.500	0.490	0.022	4.49
0.300	0.314	0.015	4.78
0.100	0.109	0.007	6.42

TABLE 6. ANALYTICAL RESULTS FOR THE VENTURI/SPRAY TOWER SLUDGE DATA

Variable	Mean	Std. Dev.	Low Values	High Values
A. Lime Product Sludge (n = 66 data points)				
ASH (wt. %)	31.5	19.11	$\leq$ 12	$\geq$ 50
CaO (wt. %)	29.3	8.66	$\leq$ 21	$\geq$ 38
SO_2 (wt. %)	24.9	9.14	$\leq$ 15	$\geq$ 34
SO_3 (wt. %)	7.1	4.88	$\leq$ 2	$\geq$ 12
CO_2 (wt. %)	1.5	1.18	$\leq$ 1	$\geq$ 2.7
Solids Recirculated (wt. %)	10.4	4.21	$\leq$ 6	$\geq$ 15
Oxidation (wt. %)	19.9	18.47	$\leq$ 10	$\geq$ 90
Settled Solids (wt. %)	43.4	8.12	$\leq$ 35	$\geq$ 52
Settled Bulk (g/cc)	1.3	0.09	$\leq$ 1.2	$\geq$ 1.4
B. Limestone Product Sludge (n = 98 data points)				
ASH (wt. %)	32.5	16.08	$\leq$ 12	$\geq$ 50
CaO (wt. %)	29.7	7.86	$\leq$ 21	$\geq$ 38
SO_2 (wt. %)	21.1	8.42	$\leq$ 15	$\geq$ 34
SO_3 (wt. %)	6.0	3.77	$\leq$ 2	$\geq$ 12
CO_2 (wt. %)	5.5	3.36	$\leq$ 2	$\geq$ 9
Solids Recirculated (wt. %)	14.6	3.34	$\leq$ 11	$\geq$ 18
Oxidation (wt. %)	21.5	21.27	$\leq$ 10	$\geq$ 90
Settled Solids (wt. %)	41.3	8.56	$\leq$ 32	$\geq$ 50
Settled Bulk (g/cc)	1.3	0.10	$\leq$ 1.25	$\geq$ 1.4

TABLE 7. MEAN VALUES FOR HIGH SETTLED SOLIDS

Variable	Lime		Limestone	
	High Oxidation	Other	High Oxidation	Other
ASH (wt. %)	55.7	33.0	64.5	38.6
CaO (wt. %)	15.6	28.9	10.3	27.4
SO_2 (wt. %)	0.5	25.8	0.2	18.2
CO_2 (wt. %)	0.3	6.0	0.7	6.7
Solids Recirculated (wt. %)	18.6	12.9	16.4	17.7
Oxidation (wt. %)	96.6	15.4	98.3	17.9
Settled Solids (wt. %)	65.0	55.1	63.3	53.2
Number of data pts.	2	5	6	5

TABLE 8. MEAN VALUES FOR LOW SETTLED SOLIDS

Variable	Lime	Limestone
ASH (wt. %)	17.0	14.0
CaO (wt. %)	37.5	38.8
SO_2 (wt. %)	25.2	27.2
CO_2 (wt. %)	2.8	7.2
Solids Recirculated (wt. %)	8.8	9.2
Oxidation (wt. %)	14.8	15.6
Settled Solids (wt. %)	26.9	26.9
Number of data pts.	6	11

TABLE 9. MEAN VALUES FOR HIGH SETTLED BULK DENSITY

Variable	Lime		Limestone	
	High Oxidation	Other	High Oxidation	Other
ASH (wt. %)	55.7	34.3	64.5	32.4
CaO (wt. %)	15.6	28.8	12.0	30.5
SO_2 (wt. %)	0.5	25.2	0.2	24.1
CO_2 (wt. %)	0.3	3.2	0.7	4.8
Solids Recirculated (wt. %)	18.6	7.6	16.4	15.2
Oxidation (wt. %)	96.6	11.4	98.3	11.4
Settled Bulk Density (g/cc)	1.65	1.43	1.61	1.43
Number of data pts.	2	4	6	4

TABLE 10. MEAN VALUES FOR LOW SETTLED BULK DENSITY

Variable	Lime	Limestone
ASH (wt. %)	7.4	11.4
CaO (wt. %)	42.7	40.2
SO_2 (wt. %)	35.5	28.2
CO_2 (wt. %)	3.5	7.5
Solids Recirculated (wt. %)	7.5	7.0
Oxidation (wt. %)	10.8	13.0
Settled Bulk Density (g/cc)	1.15	1.17
Number of data pts.	4	8

TABLE 11. PREDICTED RESPONSE FOR CHANGES IN VARIABLES-LIMESTONE SYSTEM

% Settled Solids	Settled Bulk Density	% Sulfite Solids	% Solids Recirculated
41.8	1.37	15.0	15.0
38.8	1.33	34.0	15.0
35.6	1.32	21.0	11.0
43.8	1.38	21.0	18.0
62.5	1.61	0.4	18.0
24.3	1.20	37.0	5.0

TABLE 12. COEFFICIENTS AND STANDARD ERRORS FROM REGRESSION ANALYSIS

Dependent Variable	Sludge	ln a Coef./Std. Error	b_1 Coef./Std. Error	b_2 Coef./Std Error
ln (% settled solids)	Lime	3.68/0232	-0.09/0.032	0.15/0.073
ln (% settled solids)	Limestone	2.84/0.133	-0.09/0.014	0.42/0.044
ln (settled bulk density)	Lime	0.40/0.062	-0.05/0.009	0.01/0.019
ln (settled bulk density)	Limestone	0.14/0.040	-0.04/0.004	0.09/0.013

Model: $\ln Y = \ln a + b_1 \ln X_1 + b_2 \ln X_2$

where X_1 = % sulfite solids
X_2 = % solids recirculated

TABLE 13. EVALUATION STATISTICS FROM REGRESSION ANALYSIS

Dependent Variable	Sludge	R^2[1]	F (n_1,n_2)	s^2	e^s
ln (% settled solids)	Lime	0.26	11.59 (2,63)	0.18	1.20
ln (% settled solids)	Limestone	0.63	80.51 (2,93)	0.12	1.13
ln (settled bulk density)	Lime	0.47	28.11 (2,63)	0.05	1.05
ln (settled bulk density)	Limestone	0.64	83.34 (2,93)	0.04	1.04

[1]Multiple Correlation Coefficient
[2]Standard Error of Estimate